Canadian Aeronautical

Journal

CONTENTS

THE ROOT OF THE MATTER

Orenda is pioneering many new concepts in jet engine design. The IROQUOIS supersonic turbojet, now producing over 20,000 lbs. (dry) thrust in its early development, incorporates several. The outstanding performance of the IROQUOIS, combined with inherent low weight, is the reason it has been selected for the Avro Arrow, Canada's new supersonic interceptor.

Illustration shows stress patterns in a jet engine blade root under load, using color photography and photo-elastic stress analysis.

ORENDA *ENGINES LIMITED*

MALTON, CANADA

MEMBER: A.V. ROE CANADA LIMITED & THE HAWKER SIDDELEY GROUP

SEVEN SECRETS
OF SUCCESS

The ability to produce the kind of equipment required
by an exacting industry is the secret of success.
Depicted here are seven such units, currently
being produced by Jarry Hydraulics for the Canadair "Argus". Of them, the wing flap actuator,
the up-lock jack, the steering cylinder and the
main retraction jack were designed by our engineers,
thus setting another example of Canadian
self-sufficiency in the hydraulics field.

Ball Screw Flap Actuator (8)

Steering Cylinder

Nose Landing Gear

Main Gear Up-lock Jack

Main Gear Retraction Jack

Feel Simulator

Main Landing Gear

Jarry Hydraulics

Designers and manufacturers of landing gear and
other hydraulic components for modern aircraft, including:
Argus, CF-105, CS-2F-1, F-86, T-33, Beaver, Otter.

FRESH
IMPETUS
FOR
PROGRESS

For Canadair...The Sky is NOT The Limit!

What we have learned *in the air*—we apply *on the ground*. See these snowmobile-type vehicles: they are a solution to an unique problem of transport over trackless terrain through snow, muskeg, sand or water, and were Canadair-developed and manufactured for the Canadian Armed Forces.

And Canadair's research and development division is ready to undertake other special jobs in many fields, such as: research, development problems, custom designs,

electronics, digital and analogue electronic computing, structural and mechanical testing: in all a service designed to offer fresh impetus for progress.

We invite you to get in touch with us: contact our Vice-President/Engineering.

CANADAIR
LIMITED, MONTREAL
• Aircraft • Research and Development
• Guided Missiles • Nuclear Engineering

CA57-CANT-8

INSTITUTE OF AEROPHYSICS

Exterior view showing 40 ft diameter vacuum sphere, subsonic diffuser, vacuum pump inlet pipe and bank of propane cylinders for reactivating the alumina drying unit.

EDITORIAL

MID-SEASON MEETING

IN Febuary the second Mid-season Meeting will be held in Vancouver. The majority of the Institute's members live in Ontario and Quebec and may regard this meeting as something far away, which is no concern of theirs. Nevertheless, it is an important feature of the Institute's year and, if we are to call ourselves the Canadian Aeronautical Institute, we must lay equal emphasis on all our meetings, wherever they may be held in Canada. It is to be hoped that the attendance from the east, as well as from the Branches at Winnipeg, Edmonton and Cold Lake, will demonstrate that the C.A.I. is one society and not two or even three, separated by the Great Lakes and the Rocky Mountains.

The first Mid-season Meeting was held last February in Winnipeg. It originated in a suggestion from Mr. Richmond, on his retirement from the Presidency in May, 1956, that at least one Council Meeting during the year should be held in the west. This idea was developed and eventually turned into a two-day Institute Meeting, including tours of two plants and two technical sessions, at which some good general papers were presented. About 80 members attended from the east.

This year the programme will include five technical sessions. In a departure from normal practice, the Dinner is being held on the evening of the second day; the evening of the first day is being devoted to a special technical session, which we hope will be attractive and convenient to those members of the Vancouver Branch who are unable to get away from their jobs at other times.

There are two groups of members of the Branch who will be particularly welcome at the Meeting, because of the geographical obstacles in their way. The first of these is the Student Section at the Canadian Services College, Royal Roads. This Meeting provides an excellent opportunity for our Student members to get to know some of the more experienced people in the aeronautical profession and we hope that they can overcome both the exigencies of their academic work and the Strait of Georgia sufficiently to put in at least a brief appearance. The second group comprises the members living in and around Seattle. It is nice to think that the C.A.I. offers them an excuse for a short visit home! And we hope that, when they come, they will bring some of their colleagues in the Seattle Section of the I.A.S., as their guests.

It is appropriate that the Institute should have chosen Vancouver as the site of its Mid-season Meeting in 1958; for this year is being celebrated as the Centennial of British Columbia. In 1858, to establish law and order, and incidentally British sovereignty, in the face of the great gold rush into the valley of the Fraser River, the mainland of British Columbia was made a crown colony. And so, in holding this year's Mid-season Meeting in Vancouver, the Institute is paying tribute to a hundred years of British Columbia and, let us not forget, to our hosts, the Vancouver Branch, which was the first native Branch of the C.A.I.

W. RUPERT TURNBULL LECTURER

Dr. G. N. Patterson

Dr. G. N. Patterson, Director of the Institute of Aerophysics, University of Toronto, delivered the third W. Rupert Turnbull Lecture on the 21st October, 1957. His lecture has been divided into three parts for publication in the Journal. Part 1 appears in this issue and Parts 2 and 3 will appear in February and March, respectively.

CANADIAN AERONAUTICAL INSTITUTE

THIS IS PRESENTED TO

G. N. Patterson

WHO DELIVERED THE

W. Rupert Turnbull Lecture

for 1957

ON THE OCCASION OF

The 1957 Joint Meeting between the Canadian Aeronautical Institute and the Institute of the Aeronautical Sciences held in Montreal on the 21st and 22nd October 1957.

The Lecture was established in 1955 by the Canadian Aeronautical Institute to commemorate annually the pioneering work in aeronautical engineering carried out by Dr. W. Rupert Turnbull of Rothesay, New Brunswick.

THE SUBJECT OF THIS THIRD LECTURE WAS

"Aerophysical Problems of Flight at Extreme Altitudes and Speeds"

DATE: 21st October 1957

PRESIDENT

SECRETARY

Dr. Patterson was born in 1908 in Medicine Hat and attended the University of Alberta, obtaining his B.Sc. in Engineering Physics in 1931. After doing postgraduate work in Fluid Mechanics, obtaining his M.A. and Ph.D., he went to England in 1935 and joined the Aerodynamics Department of the R.A.E. Farnborough. In 1939 he was appointed Head of the Aerodynamics Department of the Australian Council for Scientific and Industrial Research, Melbourne; he concluded his work for the Australian Government with two years of advanced studies in jet propulsions and supersonic aerodynamics at the California Institute of Technology, on which he reported back to Australia in the latter part of 1946. He returned to Canada in 1947 as Professor of Aerodynamics, University of Toronto, and was appointed Director of the Institute of Aerophysics in 1949. He has served as Chairman of the Advisory Aeroballistics Panel, U.S. Naval Ordnance Laboratory, and he is a member of the Gas Dynamics Panel, Defence Research Board.

AEROPHYSICAL PROBLEMS OF FLIGHT AT EXTREME ALTITUDES AND SPEEDS†

by Dr. G. N. Patterson*

Institute of Aerophysics, University of Toronto

SUMMARY

In order to obtain a better understanding of the aerodynamics of high-performance aircraft, it is necessary to investigate the effects of rarefaction, large Mach numbers and high stagnation temperatures. These effects show the increasingly important role played by the molecular structure of a gas in its macroscopic motion.

A consideration of the corridor of sustained flight which lies between present day aircraft and satellites indicates that hypersonic flight can occur only at high altitude. The fundamental effects of high altitude on aerodynamics and the associated regimes of low density flows are discussed. Consideration is given to the interaction of gas molecules with the surface of a solid body, the boundary layer with slip flow, and free molecule flow. Hypersonic effects due primarily to high Mach numbers are outlined, including a discussion of the limits of linearized supersonic theory, the hypersonic approximation, and Newtonian flow. Real gas effects due to high stagnation temperatures are also indicated. The properties of gases at high temperatures with emphasis on dissociation and associated relaxation effects are discussed in terms of the flow through shock and expansion waves and in the boundary layer (aerodynamic heating). A consideration of the various experimental facilities and techniques required to solve the aerophysical problems of hypersonic flight at high altitudes concludes the discussion.

INTRODUCTION

THE importance of aerodynamic research was recognized by the aeronautical pioneers. This lecture commemorates the life and work of Wallace Rupert Turnbull who said, "We cannot build on sand; let us have the research work for a foundation". It is not surprising, therefore, that Turnbull was one of the first to build a wind tunnel (1902) to help make flight a practical reality. This lecture reviews the aerophysical research which underlies our next goal — hypersonic flight at extreme altitudes.

The improvement in the performance of piloted aircraft since the first powered flight of Wilbur Wright in 1903 may be described as a kind of geometric progression. By 1947 flight Mach numbers of the order of 1 were attained and in the past ten years this value has been increased by a factor of 2½. The improvement in missile performance is even more striking.

Modern high-performance flight involves certain requirements which must be carefully considered. At a given altitude the flight speed must be sufficiently high

†The W. Rupert Turnbull Lecture for 1957 presented at the Joint I.A.S./C.A.I. Meeting in Montreal on the 21st October, 1957.

*Director.

Figure 1

Corridor for continuous flight through the earth's atmosphere (References 1 and 2)

to provide adequate lift but low enough to avoid excessive skin temperatures. For flight speeds above 1,000 ft/sec (305 m/sec) we may take the dynamic pressure necessary for lift to be about 80 lb/ft² (390 kg/m²). If a skin temperature of about 1,000°C is permissible, then a "corridor of flight" exists as shown in Figure 1. On one side of this corridor the aircraft will be too slow and on the other side too hot. This corridor would be cut off for dynamic pressures below 40 lb/ft² (195 kg/m²) and a permissible skin temperature of about 800°C. Figure 1 is a modification of a diagram prepared by Haber[1] and improved by Williams[2]. It appears therefore that sustained flight at high speed automatically implies flight at high altitude.

The tendency to increase the altitude as greater speeds are achieved is indicated in Figure 2 which shows the performance potentials of two types of vehicle — the long-range ballistic missile and the winged rocket-boost-glide vehicle[3]. These projections beyond current performances are based on the use of rocket propulsion. Figure 2 suggests the range of altitude and speed now being considered by aeronautical engineers and scientists.

The improved performance of modern aircraft is the result of the steady advance of scientific research and development in the fields of structures and materials, propulsion, instrumentation, and fluid mechanics. In this paper we shall be concerned only with the latter topic.

Figure 2
Performance potentials for missiles and aircraft (Reference 3)

The beginning of modern fluid mechanics was classical hydrodynamics. At this stage of progress a fluid was assumed to be frictionless, incompressible, continuous, and chemically invariant, and considerable attention was given to the lift force on a body. When the restriction of an inviscid fluid was dropped, the subject of aerodynamics emerged which provided a better understanding of the drag of a body. The steady improvement in the performance of aircraft soon made it necessary to remove the limitation imposed by the assumption of incompressibility and the modern subject of gas dynamics was born. The emphasis in research was now placed on the study of major compressibility effects such as the critical Mach number and shock wave phenomena. The stage has now been reached when the assumption of continuit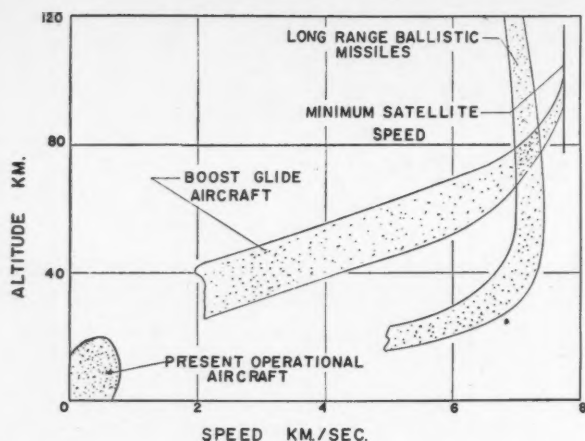y must be carefully scrutinized. It has become apparent that flight through the earth's upper atmosphere according to modern requirements involves rarefaction and high temperature effects which can only be explained on the basis of the molecular properties of gases. The advent of very high temperatures indicates that even chemical invariance may no longer be valid. It is the purpose of this paper to review some of the aerophysical problems associated with flight at extreme altitudes and speeds and to outline the test facilities which may provide the answers.

LIST OF SYMBOLS

a	radius or speed of sound according to context
B	Stefan-Boltzmann constant
C_D	drag coefficient
C_f	coefficient of skin friction
C_p	specific heat at constant pressure or pressure coefficient according to context
D	drag
E	energy of molecule or energy flux according to context
E_R	rotational energy of a molecule
g	acceleration due to gravity
h	height or distance of separation according to context
H	heat transfer per degree temperature rise per unit area per unit time
Kn	Knudsen number
l	length of body
m	mass of molecule
M	Mach number
M_w	molecular weight
n	number of molecules per unit volume
p	pressure
Pr	Prandtl number
q	macroscopic speed or heat transfer rate according to context
r	recovery factor or radius according to context
R	gas constant
Re	Reynolds number
S	speed ratio (q/c_m)
St	Stanton number
t	time
t_{max}	maximum reaction time
T	temperature
T_e	equilibrium temperature
T_o	stagnation temperature
T_w	surface temperature
u_1	components of macroscopic velocity
u_s	slip velocity
V	flight speed
$x_1(\text{or } x, y)$	position coordinates
α	thermal accommodation coefficient
α_R	accommodation coefficient associated with rotational energy of the molecule
γ	the ratio of specific heat at constant pressure to specific heat at constant volume
δ	thickness of the boundary layer
δ_m	thickness of the shock wave
ϵ	emissivity
θ, θ_b	inclination of a surface to direction of macroscopic motion
Θ	molecular vibration temperature
κ	coefficient of heat conduction
λ	mean free path
μ	coefficient of viscosity
μ_b	coefficient of bulk viscosity
ρ	density
σ_N	normal momentum accommodation coefficient
σ_T	tangential momentum accommodation coefficient
τ	shearing stress or relaxation time according to context
ω	rotational speed

Part 1. HIGH ALTITUDE EFFECTS

BASIC PHYSICAL EFFECTS OF HIGH ALTITUDE

Investigations show that the basic aerophysical effects associated with flight at both high altitude and high speed arise from fundamental changes in the molecular structure of the air. We shall consider first the physical effects due to high altitude which arise from changes in the molecular structure of the upper atmosphere and the considerably increased average distance travelled by molecules between collisions (mean free path).

The term upper atmosphere[4] may be loosely used to denote the regions of the earth's atmosphere above 30 km (18.6 mi). The lowest region of the atmosphere is called the troposphere (Figure 3). As the altitude in-
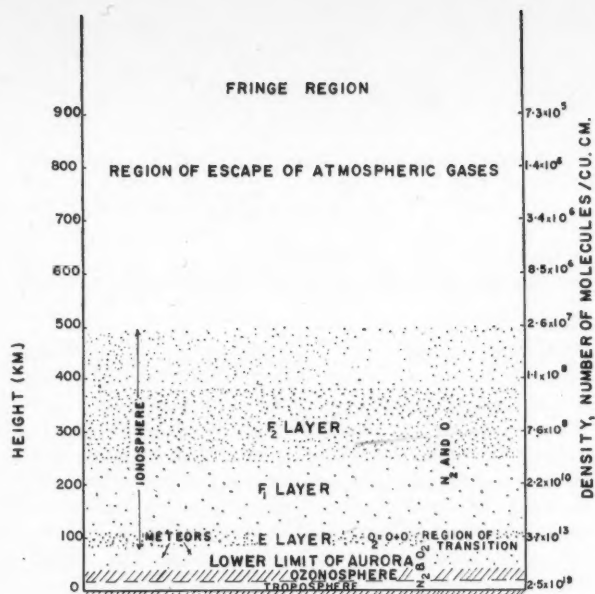
4

Figure 3
Regions of the earth's atmosphere (References 4 and 5)

(50 mi) is due to the dissociation and ionization of the upper atmospheric air.

It will be seen, therefore, that flight at very high altitude means flight in an atmosphere which has some degree of dissociation and ionization. The physical properties of this medium which are important to the aerodynamicist is the subect of intensive investigation.

Apart from the changed physical state of the air at exteme altitudes, a further effect will arise from the increase in the mean free path with height which causes fundamental changes in the flow of air around an aircraft. Sounding rockets are used to obtain pressure data in the upper atmosphere and the ambient density is determined from the measured pressure according to the

relation $\rho = -\frac{1}{g}\frac{dp}{dh}$ which does not involve the mass

of the molecule (unknown at great heights). Above 100 km (62 mi) the mean free path becomes appreciable, Figure 4, and the density must be calculated on the basis of the kinetic theory of gases.

The effect of large mean free paths on an airflow can be determined by considering the motion of a gas from a molecular point of view[6]. In the kinetic theory of gases the molecules are perfectly elastic spheres or point centers of force both of which possess only three translational degrees of freedom. The average distance travelled between collisions (or the mean free path) is a basic characteristic of the molecular motion. The ratio of the mean free path (λ) to a characteristic body dimension (l) is called the Knudsen number ($Kn = \lambda/l$). When λ is no longer negligible compared with l, the gas does not behave like a continuum. As a gas becomes more rarefied, the Knudsen number increases, and the associated rarefaction effects give rise to three essentially different kinds of flow. The first deviation from continuum flow called slip flow occurs in the

creases through this zone the temperature and pressure drop almost adiabatically. The tropopause is reached at temperatures of 200-220°K. Its height varies from 6 km (3.7 mi) above the poles to 18 km (11.2 mi) above the equator. Above the tropopause is the stratosphere, an isothermal region of about 10 km (6.2 mi) height depending on latitude. The region above the stratosphere (30 km or 18.6 mi) extending outward to interplanetary space is termed the upper atmosphere.

Above 80 km (50 mi) the atmosphere is ionized and this region is called the ionosphere. The ionosphere is subdivided according to the intensity of ionization. The E-layer is moderately ionized and it is situated at about the 100 km (62 mi) level. The F-layer is more strongly ionized and occurs at about 200-300 km (124-187 mi). A pictorial representation of the physical properties of the atmosphere is given in Figure 3[5]. This figure is illustrative only and should not be taken too literally.

Some physical properties of the upper atmosphere are shown in Figure 4 which is based on data given in Reference 4. In obtaining this information certain assumptions must be made regarding the molecules. It is considered that no change in molecular weight occurs up to a height of 80 km (50 mi). The dissociation of diatomic oxygen into atomic oxygen takes place at altitudes between 80 km (50 mi) and 120 km (75 mi) and the dissociation of diatomic nitrogen into atomic nitrogen occurs at 130-250 km (80-155 mi).

Referring to Figure 4 it will be seen that the temperature falls in the troposphere. At about 20 km (12.5 mi) this trend is reversed and the temperature rises to about 270°K at 50 km (31 mi). This rise results from an increase in the ozone content of the air and the associated absorption of solar radiation. From 50 km to 80 km (31-50 mi) this effect drops off as the ozone content decreases. Finally the rise in temperature above 80 km

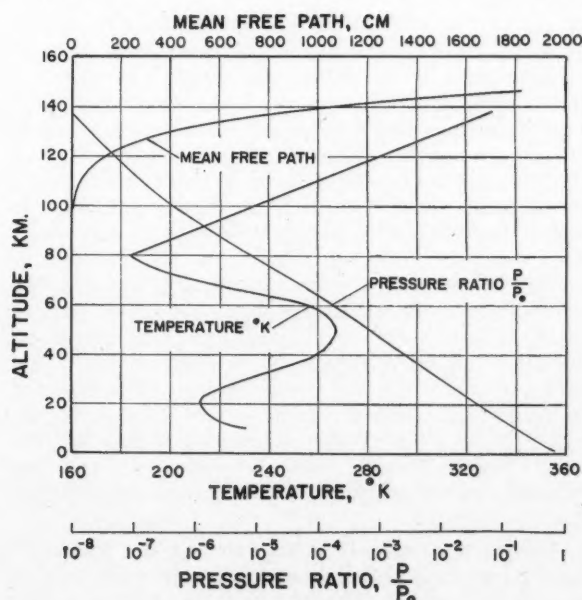**Figure 4**
Approximate physical properties of the upper atmosphere
(Reference 4)

range $0.01 < Kn < 0.1$. When the Knudsen number is very large ($Kn > 10$), free molecule flow occurs. Transition flow is found in the intermediate range $0.10 < Kn < 10$. These ranges of Kn are arbitrary, but they appear to correspond with existing experimental information[7].

INTERACTION OF A GAS MOLECULE WITH A SOLID WALL

Little progress can be made on the subject of rarefaction effects in aerodynamics without first considering the mode of encounter of a gas molecule with the surface of a body or container. In this section we shall assume that the gas molecule has a relatively low energy and reflects from the wall in a manner envisaged by the kinetic theory of gases.

We can conceive of two kinds of reflection of gas molecules from a solid boundary. If the wall were perfectly smooth it is possible that "mirror-like" or specular reflection might occur in which the component of the incident molecule normal to the surface is reversed in direction but unchanged in magnitude on contact with the wall. In practice, however, the surface is rough and contains interstices in which a gas molecule may be temporarily trapped. Furthermore, the ultimate direction of reflection may have no relation to the incident direction. This type of reflection will be described as diffuse in character. In diffuse reflection all directions of emission about the normal to the surface are equally probable, regardless of the direction of impingement. More specifically, the probability that a molecule will leave the surface at a particular angle is proportional to the cosine of the angle with respect to the normal. In general the speeds of diffusely reflecting molecules are grouped according to a Maxwellian distribution corresponding to a temperature which can be different from that of the surface.

Gas-surface interactions have been studied mainly by the molecular beam technique. The method is surveyed in References 8 and 9. In this method a stream of molecules is directed on a plane surface element and measurements of the flux of scattered molecules are made of various angles relative to the incident beam (Figure 5). The beam is produced by the thermal effusion of molecules from a small source chamber through an orifice or a tube. The molecules emitted by the source move along diverging rectilinear paths. On reaching the orifice the properly orientated molecules pass through and constitute the molecular beam, and those stopped by the orifice are drawn off by a pump. The beam passes through a region of high vacuum (10^{-6} mm Hg) and strikes the test surface at a selected angle. The scattered molecules which reflect within a small solid angle pass into a detector and produce a small increment in pressure. The detector (essentially an ionization gauge) can be moved to various positions to determine the complete flux distribution.

Of special interest to designers are the molecular beam tests of air molecules on typical materials used in aircraft construction. Hurlbut[9] finds that the cosine law of scattering is valid for the spatial flux distribution of air and nitrogen molecules reflected from polished low carbon steel, etched low carbon steel and polished
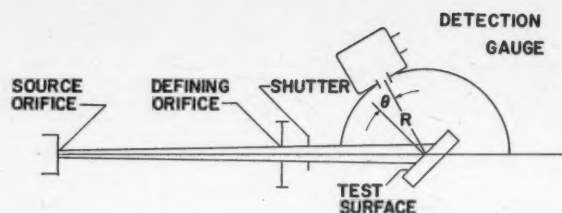

Figure 5
Measurement of the flux of scattered molecules (Reference 9)

aluminum, independent of outgassing or surface temperature. Furthermore, the reflected molecules possessed a mean energy closely consistent with the thermal condition of the wall. On the other hand when air and nitrogen molecules reflected from a glass surface, small deviations from the cosine scattering distribution were detected. These deviations could be explained by assuming that while most of the molecules are reflected diffusely, the remainder are reflected specularly. However, experiments using other surfaces and gases show that large deviations from diffuse reflection can occur, and the above method of explaining the difference is in doubt since the large deviation may not be due entirely to pure specular reflection, intermediate types of interaction being quite possible.

We can characterize the actual reflection process in a given case in terms of over-all average deviations from "completely diffuse reflection" for which the scattered (reflected) flux distribution obeys the cosine law and the emitted molecules are in Maxwellian equilibrium with the surface. We define the thermal accommodation coefficient as follows,

$$\alpha = \frac{E_i - E_r}{E_i - E_w} \qquad (1)$$

where E_i and E_r are the actual incident and reflected energy fluxes, respectively, and E_w is the emitted (reflected) energy flux for completely diffuse reflection. We have the following limiting values:

For completely specular reflection, $E_i = E_r$, $\alpha = 0$,

For completely diffuse reflection, $E_r = E_w$, $\alpha = 1$.

The transport of momentum to and from a surface in directions normal and parallel to the wall can be characterized in a similar way. For tangential momentum exchanges we define

$$\sigma_T = \frac{\tau_i - \tau_r}{\tau_i} \qquad (2)$$

where τ_i and τ_r are the actual incident and reflected fluxes of tangential momentum, respectively. Note that the definition of σ_T has the same form as α since $\sigma_T = (\tau_i - \tau_r)/(\tau_i - \tau_w)$ and for perfectly diffuse reflection, $\tau_w = 0$. Similarly for the normal momentum exchange we may write

$$\sigma_N = \frac{p_i - p_r}{p_i - p_w} \qquad (3)$$

where p_i and p_r are the actual incident and reflected fluxes of normal momentum, respectively, and p_w is the emitted normal momentum flux for completely diffuse

reflection. These momentum accommodation coefficients have the following limiting values:

For completely specular reflection, $\sigma_T = \sigma_N = 0$,

For completely diffuse reflection, $\sigma_T = \sigma_N = 1$.

If the interaction involves a combination of completely diffuse and specular reflection, then σ_N is not independent of σ_T and only one of these coefficients is needed[10]. In an actual physical case, however, it is expected that α, σ_T, σ_N will be independent.

The above accommodation coefficients will be useful for the calculation of aerodynamic forces and heat transfer. They have been defined in terms of macroscopic quantities that can be determined experimentally. The following table lists the results described in References 11 and 12.

TABLE 1

ACCOMMODATION COEFFICIENTS FOR AIR ON VARIOUS SURFACES

(a) Accommodation Coefficient for Tangential Momentum[11]

Type of Surface	Value of σ_T
Machined Brass	1.00
Old Shellac	1.00
Mercury	1.00
Oil	0.90
Glass	0.89
Fresh Shellac	0.79

(b) Thermal Accommodation Coefficient[12]

Type of Surface	Value of α
Machined Aluminum	0.95-0.97
Etched Bronze	0.93-0.95
Polished Bronze	0.91-0.94
Etched Aluminum	0.89-0.97
Etched Cast Iron	0.89-0.96
Machined Bronze	0.89-0.93
Flat Lacquer on Bronze	0.88-0.89
Polished Aluminum	0.87-0.95
Polished Cast Iron	0.87-0.93
Machined Cast Iron	0.87-0.88

At present both σ_T and α are assumed to be constant for a given gas and surface, independent of stream velocity or the temperatures of gas and surface. More comprehensive data are needed at high stream (macroscopic) velocities and high temperatures. At present it appears that we may take $\sigma_T \doteq 1$, and $\alpha = 0.9$ for ordinary aircraft materials.

The above considerations hold strictly for a monatomic gas. In a diatomic gas other forms of the thermal accommodation coefficient must be considered. For example, if the energy of a gas arises from the translation and rotation of its molecules, then the collision of such molecules with a wall will involve accommodation of the rotational energy and we must define a new coefficient.

$$\alpha_R = \frac{(E_R)_i - (E_R)_r}{(E_R)_i - (E_R)_w} \qquad (4)$$

SLIP FLOW

In the present state of the subject, rarefaction effects are considered either from the point of view of highly rarefied gases (free molecule flow) or as a modification of continuum flow produced by lowering the pressure. The transition region between these two extremes has been the subject of empirical investigation mainly since no adequate theory has been developed for this regime of flow.

Deviations from continuum flow become apparent in flight at altitudes from 20 to 50 mi. The boundary layer is affected in two ways: (a) the boundary conditions allow for a small but finite slip velocity along the wall plus a corresponding temperature jump; (b) some of the terms in the equations of motion which were previously considered to be of negligible order must now be retained.

Details of the method for determining the conditions of flow at a wall (boundary conditions) from the kinetic theory are given in Reference 6. Reflection of the molecules from the wall is considered to be such that the tangential momentum and thermal accommodation coefficients (σ_T, α) are known. The calculations yield the equation for the slip velocity on the wall,

$$u_s = k\lambda \left(\frac{2 - \sigma_T}{\sigma_T}\right) \left(\frac{\partial u}{\partial y}\right)_s \qquad (5)$$

where k is a numerical constant very close to 1, and the subscript s refers to the condition of the gas at the wall (the latter taken to be at rest). The calculation for the transfer of translational energy provides a relation for the temperature jump at the wall,

$$T_s - T_w = \frac{k\lambda}{Pr}\left(\frac{2 - \alpha}{\alpha}\right)\left(\frac{\gamma}{\gamma + 1}\right)\left(\frac{\partial T}{\partial y}\right)_s \qquad (6)$$

where Pr is the Prandtl number and $\gamma = C_p/C_v$.

Before considering the effect of rarefaction on skin friction and heat transfer, let us outline the simple case of the incompressible, two-dimensional flow between two concentric cylinders, the inner one rotating and the outer one stationary[13]. This is a particularly interesting flow since it can provide us with an experimental method for determining the accommodation coefficient for tangential momentum (σ_T). For such a flow the equation of motion is

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right) = \frac{u}{r^2} \qquad (7)$$

and the solution is

$$u = Ar + \frac{B}{r} \qquad (8)$$

This solution must satisfy the following boundary conditions:

(a) On the surface of the inner cylinder (radius a)

$$u = a\omega - u_s \qquad (9)$$

(b) On the surface of the outer cylinder

$$u = u_s \qquad (10)$$

Applying these boundary conditions we find that the drag of a cylinder with slip compared with its value without slip is as follows

$$\frac{D_0}{D} = 1 + k\,Kn\left(\frac{2 - \sigma_T}{\sigma_T}\right) \qquad (11)$$

where k depends only on the geometry of the apparatus, and $Kn = \lambda/h$ where h is the distance separating the two cylinders. Since $\lambda = 1.26\,\mu\,\sqrt{\gamma/\rho}a$, Eq. (11) can also be written

$$\frac{D_0}{D} = 1 + \frac{k'}{p}\left(\frac{2 - \sigma_T}{\sigma_T}\right) \qquad (12)$$

where k' depends on μ, R, T, γ, and the geometry of the apparatus. It will be seen, therefore, that the inverse drag is a linear function of the inverse pressure[13].

The concentric, rotating cylinder method for studying rarefaction effects has been used by Stacy[14], Van Dyke[15] and others. In general the method consists in supporting the stationary cylinder on a calibrated torsion fibre. The amount of twist of the fibre produced by a given rotational speed of the inner cylinder is measured directly on a scale. Low pressures are held for sufficient time to minimize outgassing effects. Merlic[13] was interested in the case of air on aluminum because of the importance of this combination in flight problems. But he has also made a study of the important effect of "pressure history" which was suggested by Reference 14. In general Merlic found that for air held at 0.01 microns on a clean aluminum surface a value for σ_T of 0.9 gave good agreement between theory and experiment. On the other hand, when the system was held at 250 microns, σ_T was found to decrease with time until a value of $\sigma_T = 0.6$ was reached after six days. The reason for the decrease in σ_T with time at the higher pressure is still obscure and more tests are needed. It has been conjectured that the decrease in drag may be due to a thin surface film which increases the amount of specular reflection from the surface. Lower vacuums remove this film. It should be noted that Hurlbut[9] obtained $\sigma_T = 1$ by the molecular beam method for pressures of 0.001 microns.

We conclude that considerable study of the accommodation coefficients is still needed. They are of fundamental importance in the calculation of skin friction and heat transfer at high altitude.

THE BOUNDARY LAYER IN A RAREFIED GAS

The boundary layer in rarefied air will have a low Reynolds number and will be thick and tend to remain laminar. The thicker boundary layer gives an effectively thicker body and flow separation is more likely to occur.

The equations for the flow in the boundary layer are obtained by establishing the order of each term in the exact equations relative to two dimensionless numbers, λ/δ and δ/l, where δ is the boundary layer thickness (see Reference 6). According to this analysis both the slip velocity and temperature jump referred to free stream conditions have order λ/δ. In continuum flow slip velocity and temperature jump are neglected along with all terms in the equations of motion of order λ/δ or δ/l or higher, and the well known boundary layer equations are obtained for which the boundary conditions are $u_s = 0$, $T_s = T_w$. If terms of the order of the dimensionless slip velocity and temperature jump are retained in the boundary conditions, then terms of order λ/δ and δ/l should be retained in the equations of motion. It will be seen that rarefaction not only produces slip and temperature jump at the wall, but it is also responsible for "interaction effects" due to changes in the boundary layer equations.

The general problem of the effect of rarefaction on the skin friction on a flat plate at zero angle of incidence has been reviewed by Schaaf and Sherman[16]. One of the difficulties in analyzing the boundary layer in slip flow is the existence of the two basic numbers λ/δ, δ/l or λ/δ, λ/l. These parameters are frequently expressed in terms of the Mach and Reynolds numbers. Thus since $\delta/l \sim Re^{-\frac{1}{2}}$, then $\lambda/\delta \sim M/\sqrt{Re}$. Also $\lambda/l \sim M/Re$.

In presenting research results $M/\sqrt{Re}$ is used for $Re > 1$ and M/Re is used for $Re < 1$. Some experimental results obtained for a flat plate in the slip flow regime are summarized in Figure 6.

A comparison between theory and experiment is difficult at present because of the underdeveloped state of the theory. No satisfactory theory is available for the test range shown in Figure 6. The Reynolds number is too small for the Prandtl theory of the boundary layer to be applicable and too large for Oseen's theory of viscous flow. Furthermore M/Re (or λ/l) is not high enough to permit the application of free molecule flow theory. The direct application of the slip boundary conditions (Eqs. (5) and (6)) to the ordinary boundary layer equations for incompressible flow has yielded some results. The general effect of the modified boundary conditions is to reduce the displacement thickness, skin friction, and heat transfer. The decrease in the boundary layer displacement is given by[17]

$$\frac{\delta_*}{x} = \frac{1.73}{\sqrt{Re}}\left(1 - 0.866\,\frac{M}{Re}\cdots\right) \tag{13}$$

but the change in the skin friction coefficient is of lower order.

On the other hand some results show a tendency to depend on M and Re separately. In fact References 18, 19 and 20 indicate that an increase in the local skin friction coefficient can be expected due to the interaction between the boundary layer and the free stream pressure disturbance induced by the boundary layer. Although Figure 6 suggests that rarefaction effects can be analyzed in terms of the single parameter $M/\sqrt{Re}$, a closer inspection shows additional interrelations and we must conclude that no such single correlation of $C_D M$ vs $M/\sqrt{Re}$ actually exists.
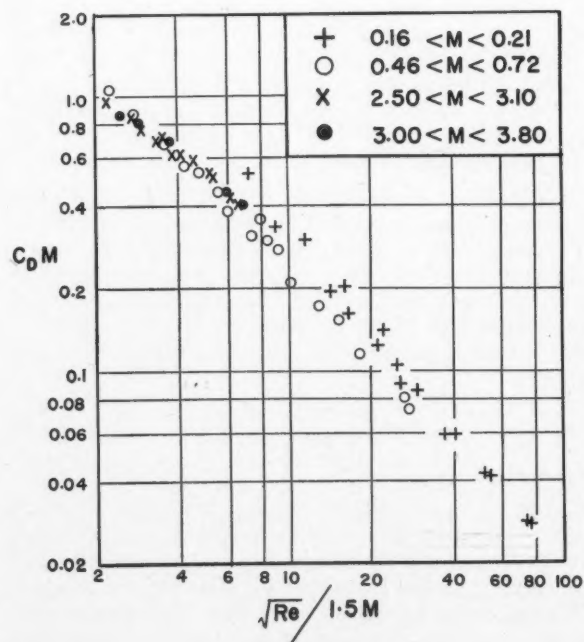

Figure 6
Rarefaction effects on the drag of a flat plate (Reference 16)

It is apparent, therefore, that the effects of rarefaction on the skin friction coefficient have at least two aspects. Interaction effects increase the skin friction, the effects becoming larger as the Mach number goes up, and they are dominant for Re in the vicinity of 1,000. However, when Re is reduced to something of the order of 50, slip effects become predominant, and the skin friction decreases with increasing Mach number. The latter is true for $M/\sqrt{Re} \doteq 1$.

As regards the more general problem it may be possible to find an asymptotic series type of solution which will correct the ordinary boundary layer theory for the neglected terms in the flow equations and allow for the slip velocity and temperature jump at the wall[16].

The rarefaction effect on heat transfer in the boundary layer is probably best seen by its action on the recovery factor[21]. For experimental reasons the flat plate is replaced by a cylinder. The equilibrium temperature of a cylinder (T_e) in free molecule flow has been considered in Reference 6, and Reference 21 indicates good agreement between theory and experiment. It is well established that in free molecule flow the equilibrium temperature of a cylinder (T_e) is greater than the stagnation temperature (T_0) $(r > 1)$, and in continuum flow an insulated body can only have a temperature equal to or less than the total stream temperature $(r \leq 1)$. In the transition region between free molecule and continuum flow the recovery factor depends on a number of parameters and it is difficult to give a simple graph of the variation of r (Figure 7). In free molecule flow the equilibrium temperature is a function of the speed ratio (S) only. The results in Figure 7 indicate that the data can be correlated by the Knudsen number for $0.02 \leq Kn \leq 2.0$ since no systematic effects due to Mach number appear. Rarefaction effects are apparent for $Kn > 0.2$ where $r > 1$. For $Kn < 0.2$, r is a constant less than 1.0 independent of the Reynolds number.

THE LIMIT OF FREE MOLECULE FLOW

We have seen that free molecule flow will exist if the characteristic dimension of a body is less than about one-tenth of the mean free path. Reference to Figure 4 shows that very large mean free paths occur in the upper atmosphere and that free molecule flow might be expected above 120-130 km (or 75-100 mi, say). It should be noted, however, that although the mean free path may be considerable, the number of molecules in the basic element of volume is still large. For example, when the mean free path in the upper atmosphere is 10 ft, the number of molecules in a cubic inch is still about 10^{13}. The usual definition of the macroscopic properties of a gas (p, ρ, T, q) through the velocity distribution function is still valid[6].

The basic characteristic of free molecule flow is that, on the average, molecular collisions are very remote from the body, and the transport of mass, momentum, and energy to a surface by the incident molecules is independent of the transfer of these quantities away from the surface by the reflected molecules. In other words we can treat the incoming and emergent streams of molecules separately[22, 23, 24]. The absence of molecular collisions implies that no macroscopic changes will be
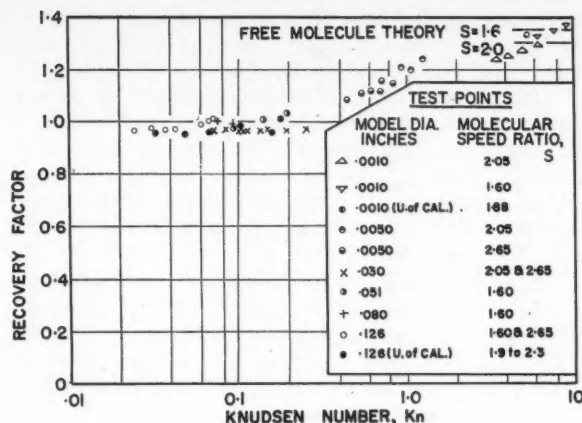

Figure 7
Variation of recovery factor with Knudsen number for a transverse cylinder (Reference 21)

produced in the gas motion by the body — there will be no boundary layer or shock waves. In fact the gas cannot macroscopically sense the presence of the body. Basically, all that is involved is a reflection process.

On the assumption that the transport processes of the incident and reflected molecules are independent (free molecule flow) the coefficient of normal pressure acting on a flat plate inclined at an angle θ to the direction of the mass flow is given by[6]

$$C_p = \sin^2\theta \left[\frac{1}{S_N} \left(\frac{1}{\sqrt{\pi}} + \frac{1}{2S_N} \sqrt{\frac{T_r}{T_i}} \right) e^{-S_N^2} \right.$$
$$\left. + \left(1 + \frac{1}{2S_N^2} + \frac{\sqrt{\pi}}{2S_N} \sqrt{\frac{T_r}{T_i}} \right) (1 + \mathrm{erf}\, S_N) \right] \quad (14)$$

The corresponding relation for the coefficient of skin friction is

$$C_f = \sin\theta \cos\theta \left[\frac{1}{\sqrt{\pi}\, S_N} e^{-S_N^2} + 1 + \mathrm{erf}\, S_N \right] \quad (15)$$

In these relations $S_N = S \sin\theta$ where S is the speed ratio, and it has been assumed that $\sigma_N = \sigma_T = 1$.

The resultant force on the flat plate depends on the ratio of the temperatures associated with the reflected and incident molecules (T_r/T_i) as well as the speed ratio and angle of incidence. This temperature ratio can be calculated from the energy balance equation, usually involving radiation effects, and the accommodation coefficient[6].

When the speed ratio becomes very large (hypersonic condition in free molecule flow),

$$C_p \to 2\sin^2\theta, \quad C_f \to 2\sin\theta\cos\theta \quad (16)$$

The first limit (C_p) will hold only if T_r/T_i remains finite while S becomes large. The physical significance of these limits can be readily seen. As the speed ratio becomes very large, the macroscopic mass velocity of the molecule becomes much greater than the most probable speed of the random motion, and the molecular motion assumes effectively a simple form in which all molecules are moving in parallel paths at the same speed. Then the number of molecules striking unit area in unit time is $nu \sin\theta$. The total normal and tangential

momentums carried by the incident molecules to unit area of the surface are $\rho u^2 \sin^2 \theta$ ($\rho = mm$), and $\rho u^2 \sin \theta \cos \theta$, respectively. The limiting values given in Eq. (16) above imply that the reflection process makes no appreciable contribution to the normal momentum — that is the normal momentum of the incident molecule is "destroyed". Of course, the random nature of the reflection is such that the emergent molecules make no resultant contribution to tangential momentum for any value of the speed ratio[6].

The above limits are determined on the assumption that the kinetic theory of gases can provide an adequate description of the reflection process. However, when the incident molecules have very high energies, the collisions with the wall may deviate appreciably from the elastic type, i.e. they may become "plastic". When high energy molecules are temporarily trapped by the wall, they may be capable of exciting rotations and vibrations of the crystal atoms. The vibrational amplitude of the atoms of

an iron crystal may be increased to such an extent that local melting occurs on the wall. In this connection it is interesting to note that for melting of iron an energy of 0.6 eV per atom is required. On the other hand the kinetic energies of a nitrogen molecule at speeds of 100 and 10,000 m/sec are about 0.001 and 12.2 eV, respectively[25]. It appears to be possible that the temperature associated with the translational motion of the molecules emerging from the wall will become high compared with the temperature of the incident molecules as the speed ratio increases (T_r/T_1 becomes large as $S \to \infty$). Therefore the limiting value for C_p given in Eq. (16) above may be more accurate if the ratio T_r/T_1 is retained in some form.

It is also possible that the reflection process will involve dissociation and ionization of the emergent gas molecules. The subject of the reflection of high energy molecules from a wall must be left for further theoretical and experimental investigations.

REFERENCES

(1) Haber, F. — *The Heat Barrier*, Scientific American, December, 1953.

(2) Masson, D. J. and Gazely, C. Jr. — *Surface Protection and Coating Systems for High-Speed Flight*, Aero. Eng. Rev., p 46, November, 1956.

(3) Pearson, E. O. Jr. — *Introductory Remarks Concerning Some Aspects of Hypersonic Research and Research Facility Requirements*, presented to Advisory Group for Aeronautical Research and Development, Scheveningen, Holland, July 8-12, 1957.

(4) Kallman, H. K. — *Physical Properties of the Upper Atmosphere*, RM-841, Rand Corporation, Santa Monica, Calif., 1952.

(5) Mitra, S. K. — *General Aspects of Upper Atmospheric Physics*, Proceedings of Conference on Ionospheric Physics, Part A, No. 11, Geophysics Research Div., Air Force Cambridge Research Center, Cambridge, Mass., 1950.

(6) Patterson, G. N. — *Molecular Flow of Gases*, John Wiley & Sons, New York, 1956.

(7) Schaaf, S. A. — *Rarefied Gas Dynamics*, Applied Mechanics Reviews, Vol. 9, No. 10, p 413, 1956.

(8) Smith, K. F. — *Molecular Beams*, Methuen & Co., 1955.

(9) Hurlbut, F. C. — *An Experimental Molecular Beam Investigation of the Scattering of Molecules from Surfaces*, Report No. HE-150-118, Institute of Engineering Research, University of California, 1953.

(10) Bell, S. and Schaaf, S. A. — *Aerodynamic Forces on a Cylinder for the Free Molecule Flow of a Nonuniform Gas*, Jr. Am. Rocket Soc., Vol. 23, p 314, 1953.

(11) Millikan, R. A. — *Coefficients of Slip in Gases and the Law of Reflection of Molecules from the Surfaces of Solids and Liquids*, Phys. Rev. Vol. 21, p 217, 1923.

(12) Wiedmann, M. L. and Trumpler, P. R. — *Thermal Accommodation Coefficients*, Trans. A.S.M.E., Vol. 68, p 57, 1946.

(13) Merlic, E. — *An Experimental Determination of Reflection Coefficients for Air on Aluminum*, Institute of Engineering Research, University of California, Report No. HE-150-141, 1956.

(14) Stacy, L. J. — *A Determination by the Constant Deflection Method of the Value of the Coefficient of Slip for Rough and Smooth Surfaces in Air*, Phys. Rev., Vol. 21, p 239, 1923.

(15) Van Dyke, K. S. — *The Coefficients of Viscosity and Slip of Air and Carbon Dioxide by the Rotating Cylinder Method*, Phys. Rev. Vol. 21, p 250, 1923.

(16) Schaaf, S. A. and Sherman, F. S. — *Skin Friction in Slip Flow*, Jr. Aeronaut. Sci., Vol. 21, No. 2, p 85, 1954.

(17) Lin, T. C. and Schaaf, S. A. — *The Effect of Slip on Flow Near a Stagnation Point and in a Boundary Layer*, NACA Tech. Note No. 2568, 1951.

(18) Alden, H. L. — *Second Approximation to the Laminar Boundary Layer Flow Over a Flat Plate*, J. Math. and Phys., p 91, April, 1948.

(19) Lees, L. and Probstein, R. F. — *Hypersonic Viscous Flow Over a Flat Plate*, Princeton University, Aero. Eng. Lab. Report No. 195, 1952 .

(20) Lees, L. — *On the Boundary Layer Equations in Hypersonic Flow and Their Approximate Solutions*, Princeton University, Aero. Eng. Lab., Report No. 212, 1952.

(21) Stalder, J. R., Goodwin, G. and Creager, M. O. — *Heat Transfer to Bodies in a High-Speed Rarefied-Gas Stream*, NACA Report No. 1093, 1952.

(22) Stalder, J. R. and Jukoff, D. — *Heat Transfer to Bodies Travelling at High Speed in the Upper Atmosphere*, NACA Report No. 944, 1949.

(23) Loeb, L. B. — *The Kinetic Theory of Gases*, McGraw-Hill Book Co., New York, 1934.

(24) Knudsen, M. — *Die molekulare Wärmeleitung der Gase und der Akkommodationskoeffizient*, Annalen der Physik, Vol. 34, p 593, 1911.

(25) Sänger, E. — *Gaskinetik sehr grossen Flughöhen*, Schweizer Archiv für angewandte Wissenschaft und Technik, Vol. 16, p 43, 1950.

ICE CRYSTALS — A NEW ICING HAZARD†

by O. R. Ballard* and B. Quan**

*D. Napier & Sons Ltd. and
National Research Council*

SUMMARY

Recent flight experience in ice crystal clouds has focused attention on an icing problem previously ignored.

The nature of these clouds and the effect of crystal ice formation on anti-icing systems designed for supercooled droplet icing are considered.

Various methods of simulating icing conditions are reviewed and the methods used at the National Research Council of Canada for full scale gas turbine tests are described.

The importance of ice detection systems which distinguish between supercooled and ice crystal clouds is pointed out.

More extensive meteorological data concerning the occurrence of ice crystal and mixed clouds is required to predict the likely frequency of encounters. The severity of the problem can then be assessed in the light of this further data.

INTRODUCTION

DURING recent months, renewed interest in icing problems has been brought about due to difficulties which have been encountered when flying through ice crystal clouds. In the past, only supercooled liquid water clouds were considered by designers to be an icing hazard, but recent experience has drawn attention to the fact that in some circumstances ice crystal conditions must be taken into consideration when designing anti-icing systems[1]. This paper is a review of the factors involved in the light of present knowledge and some of the recent work in this field is discussed.

METEOROLOGICAL ICING CONDITIONS

Subzero temperature clouds can exist in two forms: supercooled water droplets and ice crystals. NACA work suggests that, over the limited range they have investigated, ⅔ of clouds at −10°C are ice crystals, while at −40°C all clouds are ice crystals.

Over a number of years, the properties of supercooled clouds have been investigated and sufficient evidence has been collected to enable icing standards to be drawn up so that systems might be designed to meet the conditions. Icing standards vary in different countries but there is a general measure of agreement on the order of the quantities involved. As there is a fair amount of published data on supercooled cloud conditions, it will not be discussed in detail here. Precise information on ice crystal clouds, however, is limited since in the past

†Paper read at the Annual General Meeting of the C.A.I. in Ottawa on the 28th May, 1957.
*Assistant Chief Icing Engineer.
**Assistant Research Engineer.

they had not generally been regarded as hazardous and, therefore, little data has been collected.

Recent difficulties in flight through ice crystal clouds have occurred over the tropical regions of Africa, which are subject to vigorous movement of air masses due to the high rate of ground heating. The crystal conditions are generally found in the decaying tops of cumulonimbus clouds. During recent flights, meteorological data was collected, but this is unpublished so far as a great deal of work is involved in the reduction of the results; therefore, precise information on factors such as extent, water content, particle size and form are not available yet. However, in general terms, the magnitude of the quantities is considered to be of the order of 6 gm/m³ maximum water content and say 3 mm largest crystal size; but most crystals (say 90% by number) under 0.15 mm (150 microns). The altitude of encounters is in the 20,000 to 30,000 ft region. Observations during flights over the area suggest that crystal conditions may extend several hundred miles.

Ice crystal clouds develop from supercooled ones by a growth process. Once a few crystals are present, these will grow in size because a cloud which is saturated with respect to supercooled water will be supersaturated with respect to ice. As the crystals grow, water will evaporate from the supercooled droplets to maintain saturation of the air. This process continues until the whole cloud consists of ice crystals. Clearly, during the process, the cloud will consist of part ice crystals and part supercooled water. This transient condition is termed a mixed cloud and may last an hour or so. No information available to date gives any clue to the frequency of occurrence of mixed clouds.

MECHANISM OF ICE FORMATION

Under normal circumstances, flight through ice crystals presents no difficulties, as the impinging crystals, being ice, glance off the cold surfaces. However, if the surfaces are heated above 0°C, they will run wet and the impinging crystals will adhere and partially or completely melt, depending on the amount of heating. Surfaces may be heated by:

(a) the kinetic effect of forward speed,

(b) an anti-icing system,

(c) components running at a high temperature in a powerplant.

In order to elaborate on the conditions under which ice crystals will adhere, it is necessary to consider the heat balance occurring on a surface subject to icing.

Consider an icing surface subject to impingement of supercooled water with the surface just perceptibly wet, i.e. freezing fraction approaches unity. (The freezing fraction is defined as the proportion of the impinging water which freezes at the point of impact.) Under these conditions:

Heat is being lost by (a) convection q_c
                       (b) evaporation   . q_e
                       (c) heating of impinging
                           water from ambient
                           temperature to 0°C q_w

Heat is being added by (a) kinetic and viscous
                           heating effects q_k
                       (b) latent heat of fusion
                           of accreting ice q_t
                       (c) heat from anti-icing
                           system (if any) q_a

This may be written in equation form:

$$q_t + q_k - q_w - q_c - q_e + q_a = 0 \qquad (1)$$

Now consider the case in which the icing surface is subject to supercooled water impingement such that the surface is wet but just ice free, i.e. freezing fraction = 0. The term q_t disappears and the equation for this condition becomes

$$q_k - q_w - q_c - q_e + q_a = 0 \qquad (2)$$

We will now consider the case in which the surface is subject to the impingement of ice crystals. If the surface temperature is below 0°C, crystals will not adhere; if it is at 0°C, the surface will be wet and crystals will adhere. In order that the surface remains clear of ice, an extra term enters the heat balance equation, namely the heat required to melt the ice q_t, which will be opposite in sign to that in Eq. (1). For a surface running wet but ice free under conditions of ice crystal impingement, the heat balance equation will be

$$- q_t + q_k - q_l - q_c - q_e + q_a = 0 \qquad (3)$$

where q_l is the heat required to raise impinging crystals from ambient temperature to 0°C.

If less heat than the value of q_a required to balance the above equation is supplied, the ice crystals will partially melt and build up. As the term q_t is under most circumstances fairly large, this condition will apply over a wide range of heat inputs.

It is this set of conditions that constitutes the crystal icing hazard, particularly if the build-up occurs in some vital region, such as an engine intake.

EFFECT OF ICING IN FLIGHT

Flight through supercooled clouds will result in build-up of ice on the forward facing airframe surfaces and on engine components in the path of engine intake air. These ice accretions increase airframe drag and decrease engine performance. Axial flow compressors are particularly sensitive to ice, which builds up rapidly on inlet guide vanes and the first rows of rotor and stator blades.
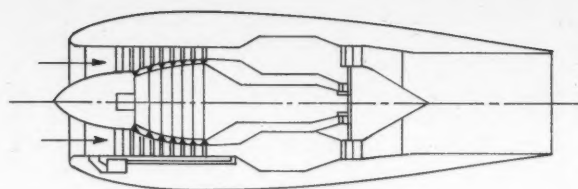

Figure 1
Pure jet engine with forward facing air intake

In general, an unprotected engine with a forward facing axial flow compressor could lose quite a large proportion of power within a few minutes in supercooled cloud conditions.

Crystal ice presents a different problem, for it has been seen that in order for the crystals to be caught the collecting surfaces must be above 0°C. Airframe icing can be avoided by the simple expedient of keeping any thermal ice protection system turned off; this emphasizes the need for a detection system which can differentiate between supercooled and ice crystal clouds.

In the case of engines the extent to which build-up of crystal ice occurs is influenced by the engine configuration. An engine of the type shown in Figure 1, with its air intake direct into the compressor, would be less affected by ice crystals than an engine layout such as that shown in Figure 2. This latter layout involves ducting the intake air through a 180° bend and in close proximity to the combustion chambers. Ice crystals would be caught on any of the duct surfaces which were subject to impingement and happened to be above 0°C. This heating could come from the engine or from operation of the anti-icing system. Now the amount of heat required to keep a surface completely free of ice crystals is a good deal larger than the heat requirement for anti-icing in supercooled droplet conditions. If we consider a few typical conditions, this can readily be demonstrated. Figure 3 is a plotting of the surface heat requirements to keep ice free under supercooled droplet conditions and ice crystals. The case chosen was at stagnation on a 2 in diameter cylinder and the catch of
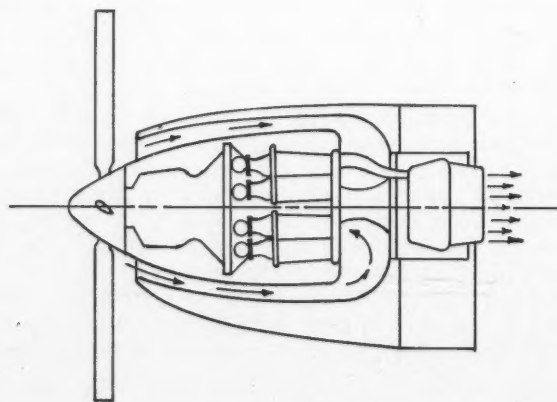

Figure 2
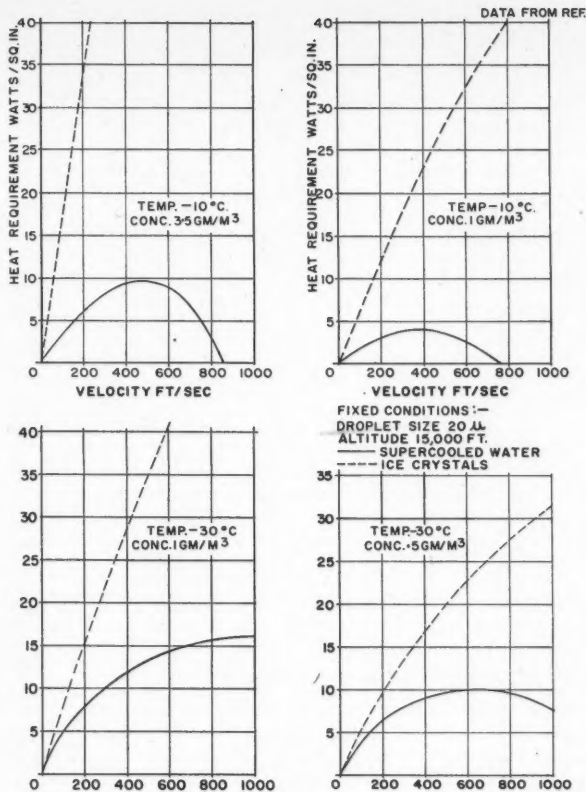**Turboprop installation with reverse flow air intake**

Figure 3

Surface heat requirements for ice prevention at the stagnation point on a 2″ diameter cylinder

ice crystals has been assumed to be the same as water droplets, due to the lack of any impingement data on crystals. It will be seen that, in the case of supercooled droplets, ambient temperature has the greatest effect on heat requirement, whereas in the ice crystal case concentration has the largest influence. This is due to the additional latent heat term necessary to melt the ice, as was discussed previously. (Eq. (3) applies.) It is of interest to note that this extra heat term required for crystals completely outweighs the kinetic effects at higher velocities, which cause the downward trend of the curves in the case of supercooled droplets.

Figure 4 is a diagram showing the various components of the total surface heat requirement at stagnation on a 2 in diameter cylinder at two concentrations and over a range of temperatures. The very large additional heat requirement of the latent heat of fusion of the ice crystals can readily be seen. (Figure 5 from Reference 2, showing the effect of other variables on the anti-icing heat requirement, has been added for reference.) It is clear that even the most efficient anti-icing system would be unable to supply the vast amounts of heat required to keep the surfaces ice free. Moreover, since it has been seen that collection of crystals will occur over a wide range of heating, much less trouble would be experienced if the anti-icing system were turned off during crystal icing encounters. If crystal ice does build up in an engine intake and a mass of ice is detached and passes suddenly into the compressor, engine performance may be affected. This manifests itself as momentary drops in engine speed or, in severe cases, extinction of the combustion (flame-out).

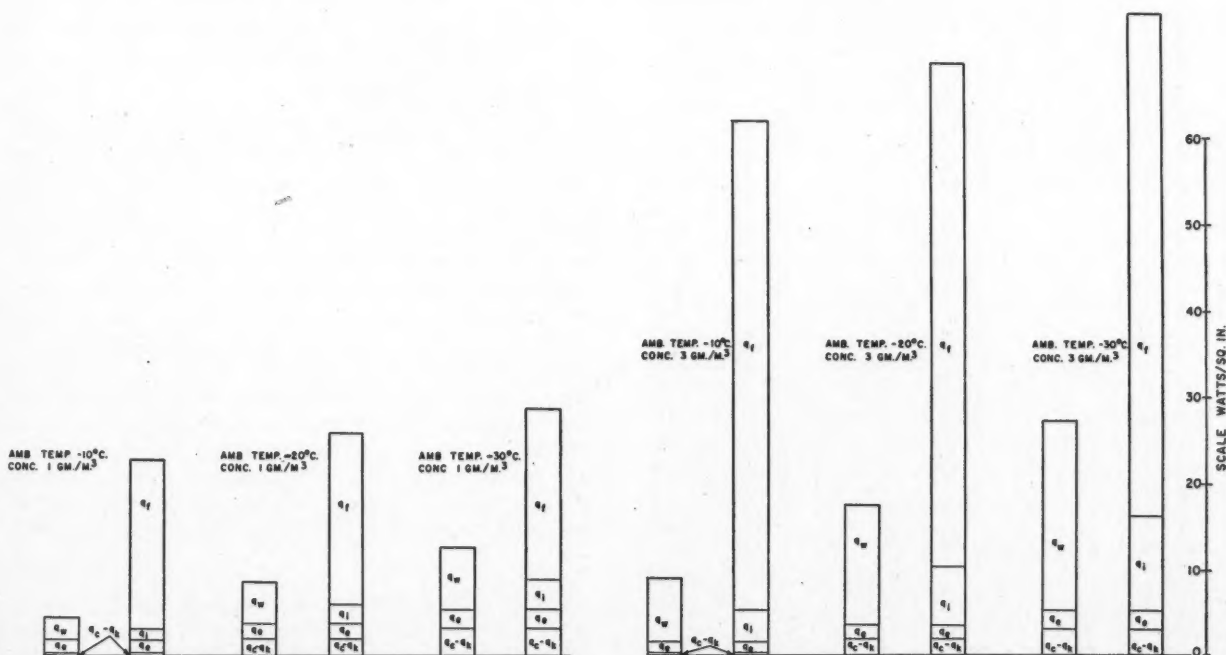Up to the moment we have considered clouds wholly of ice crystals. Flight through a mixed cloud can cause

Figure 4

Comparison of surface heat requirements for ice prevention in supercooled water and ice crystal conditions at stagnation on a 2″ diameter cylinder
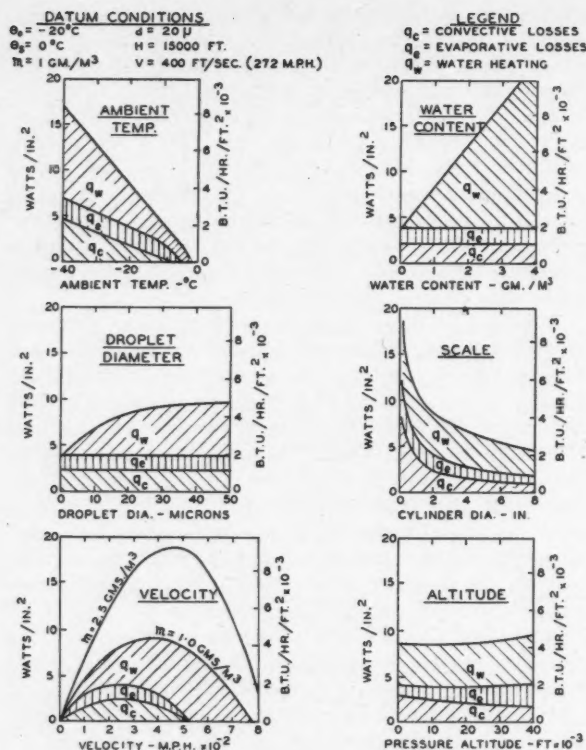
Figure 5
Variation with major parameters of external heat requirements for ice prevention at stagnation point on a 2" diameter cylinder

ice to build up on an unheated surface, provided that conditions are such that there is sufficient supercooled water present to make the surface run wet. Ice crystals will then be caught on the wet surface and will build up as was mentioned earlier. Meteorological data does not exist from which any indication can be drawn as to the extent of mixed clouds, but the probability is that, as the state is unstable, the extent is likely to be limited. Should evidence to the contrary be established in the future and mixed clouds be proved to be extensive, then a problem more serious than that of pure crystal clouds will have to be faced. Whereas, in most circumstances, turning off the anti-icing heat will prevent crystal build-up in a pure crystal cloud, the only way to keep surfaces clear in mixed cloud conditions would be to apply sufficient heat to melt the crystals. Such heating would be somewhere between the supercooled water case and the ice crystal case discussed previously and would, of course, depend on the ratio of water and crystals present in the mixture.

SIMULATED ICING CONDITIONS

First of all consider the necessity for simulation of icing conditions. It is quite difficult to find natural icing conditions in flight when they are needed and more difficult still to find a specified set of icing conditions. On a new engine design it is essential that the ice protection system be proved early so that modifications can be made before the production stage. The obvious solution then is to simulate icing conditions either on the ground or in flight.

Much useful work can be carried out using ground simulation, which has advantages in that conditions can be more closely controlled and observations of ice accretion can be made readily during and after the tests. As the effects of forward speed and altitude are difficult to reproduce on the ground, flight tests using icing simulation equipment have to be made. This equipment consists of spray nozzles, mounted ahead of the engine intake, to supply supercooled droplets and the necessary compressed air and water services. Because of the high expenditure of time and money which flight testing involves, it is very important to obtain the maximum amount of information from ground tests.

Although the problem of ice crystal accretion has been previously encountered in aerofoil icing on the North Star icing research aircraft and in tunnel work at the National Research Council[2, 3], until the past year no flight incidents had been reported with engines so that ice crystal simulation had not been needed. At the beginning of the season the requirement for the testing of engines under simulated crystal conditions arose and it became necessary to devise and produce a workable system in a short time. The system, which proved successful, is described later in the paper.

Another condition which has been successfully simulated is the sudden release of ice crystal deposits in the intake ducting or the shedding of ice from compressor blades. Although most gas turbine engines are tested on the ground without aircraft intake ducting, a later aircraft application may involve ductwork which is prone to collect ice. It is desirable to be able to predict the effect on engine performance of the release of a specified quantity of ice into the engine intake.

So far as is known, no one has tackled the problem of simulating ice crystals in flight.

METHODS OF SIMULATION

There are several methods of producing supercooled water droplets. They are: (a) spinning disc, (b) expansion turbine, (c) condensing steam, (d) hydraulic nozzles, and (e) pneumatic nozzles.

The method in most common use and the one which is used by the National Research Council is the pneumatic nozzle which uses compressed air to atomize a stream of water.

Ice crystals may also be simulated in several ways: (a) by seeding out a supercooled spray, (b) by operating pneumatic spray nozzles under freeze-out conditions, (c) by spraying water into a very cold ambient temperature, (d) by crushing ice and screening with fine screens, and (e) by cutting ice with a serrated cutter. As none of these methods produces crystals in the true sense of the word, the products will be referred to as ice particles.

Seeding

Because the droplets are in the spray duct for only a short time, the seeding techniques used for rainmaking are not directly applicable. However preliminary tests were carried out spraying a colloid of one part of silver iodide to ten thousand parts of water with a view to raising the freeze-out temperature. Initial results were

14

Figure 6
Ice trough and circular saws

not promising and attention was concentrated on alternative methods of ice particle production.

Pneumatic nozzles

If pneumatic nozzles, which are ordinarily used for producing supercooled droplets, are operated at low water flow rates and with high pressure unheated air, ice particles will be produced. However, their sizes are below 15 microns which is too small to simulate natural ice crystal conditions.

Water spray

If water is sprayed into the top of a very cold chamber (i.e. below the spontaneous freeze-out temperature) and allowed to descend, ice particles will result. This method produces particle sizes representative of natural conditions.

Crushing and screening

If ice is crushed at low temperatures ($-20°C$), it will break up into a range of sizes which can be graded by screening. The Royal Aircraft Establishment has found that handling and dispensing must be done below $-15°C$ to avoid packing and coagulation of the particles.

Serrated cutter

If a block of ice is fed into a rapidly revolving serrated cutter, ice particles of 1,000 microns and smaller are produced. These particles are considered, on the basis of present meteorological information, to be representative of natural conditions. By varying the rate of feed to the cutter, any ice particle concentration can be pro-

duced continuously and the storage problem is thereby eliminated. This method was used at the National Research Council during engine tests last season.

The equipment consisted of a bank of $8\frac{1}{4}''$ circular saws mounted on a $1\frac{3}{8}''$ arbor with $0.060''$ spacers between the blades, set at the end of an ice trough (Figure 6). Blocks of ice $6'' \times 11\frac{1}{2}''$ cross section were fed at a controlled rate into the saws. The ice particles were blown clear of the saws and down the hopper by jets of compressed air. At the bottom of the hopper, the ice particles were induced into the stream of air from the blower and passed along the distribution duct up to the four nozzles. The operation of the equipment was more satisfactory below $-10°C$ as the saws tend to clog above this temperature.

Figure 7 is a photomicrograph of an oiled slide sample of the ice particles produced. To estimate the volume of the irregularly shaped particles, they were melted with an infra-red lamp to form spherical droplets (Figure 8). It is thought that a certain amount of evaporation took place during the melting so that further development of this technique is required.

The equipment used to simulate a sudden release of ice into the engine consisted of a compressed air gun comprising three 3 in barrels, each supplied with air by
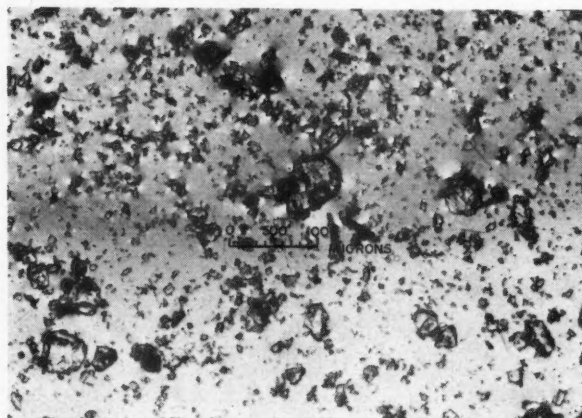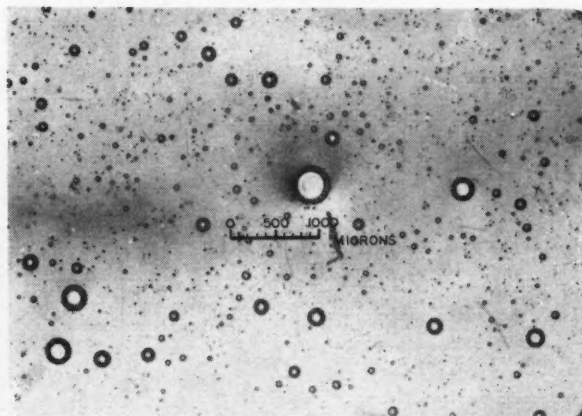

Figure 7
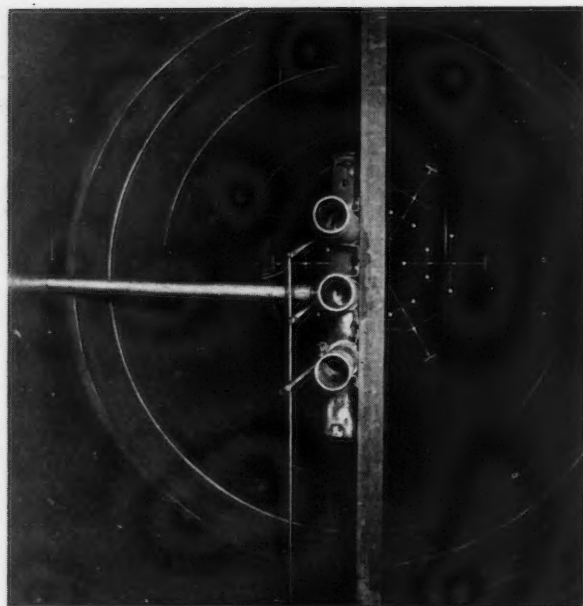**Ice particle sample**

Figure 8
Ice particle sample after melting

Figure 9
Compressed air gun for ice ingestion tests

Figure 10
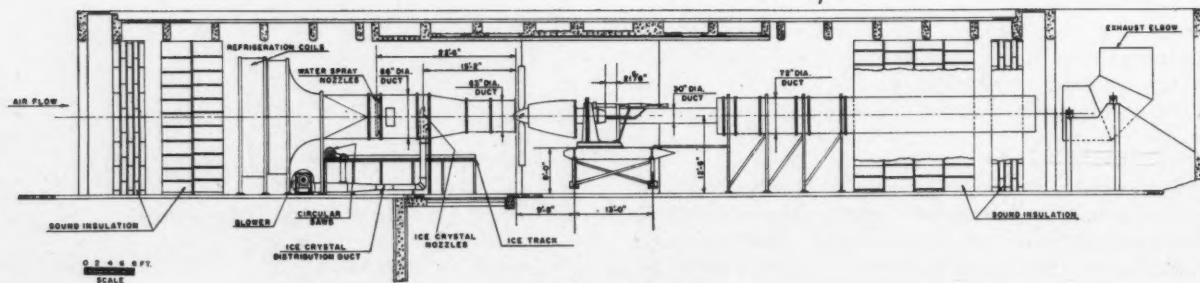**Installation for ice particle tests on a turboprop**

a quick acting valve. Using 100 psi air with the arrangement shown in Figure 9, known quantities of ice can be injected into engine intakes in about ¼ sec. The barrels were located about 10 ft from the engine intakes.

ENGINE TESTS

Figures 10 and 11 show a turboprop engine set up for icing tests on one of the National Research Council test cells. For supercooled tests the ice particle nozzles are removed. The long duct is fitted to ensure that the water droplets have time to fully supercool to ambient temperature. For simulated crystal tests, the ice particle nozzles (Figure 12) are located closer to the intake to minimize fall-out of the larger particles. A mixed cloud can be produced by introducing water spray in addition to the ice particles.

With this set-up, a series of tests was made on a turboprop engine with ice particle concentrations up to 5 gm/m³. During the first test with full engine and cowl anti-icing heat on, at an ambient temperature of −23°C and ice particle concentration of 2 gm/m³, two sudden compressor speed drops occurred after 30 min of icing These compressor speed drops were of the same magnitude as those experienced in flight in natural ice crystal conditions. Inspections of the cowling passages and engine intake tunnels after several runs confirmed that the ice deposits were similar to those experienced in flight. This evidence indicated that test conditions simulated natural ice crystal cloud closely.

Ice crystal accretion has been minimized by applying deflector shields over the vulnerable warm impingement areas. A further safeguard against the effects of ice ingestion has been provided by fitting glow plugs in the combustion chambers to supply continuous ignition sources for relighting. (These remedies were developed by the engine manufacturer.)

Ice particle ingestion tests were made on two turbojet engines with the compressed air gun. Known weights of ice particles were injected into the engines at varying engine speeds and temperatures to simulate the sudden release of ice particle deposits or the sudden shedding of compressor blade ice. Because of limitations of time and equipment, the quantities of ice ingested and the ambient temperatures covered were not extensive.

It is hoped to be able to correlate ice ingestion with engine performance changes after experience with more engines.
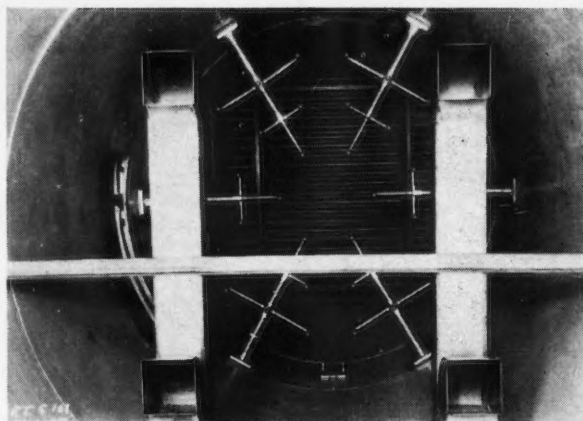

Figure 11
Installation in No. 4 test cell 1956-57

Figure 12
Ice particle nozzles

a change in icing conditions, and control the ice protection accordingly. Impingement surfaces known to be above 0°C must be shielded by deflectors to keep them cold in ice crystal conditions; however, the deflectors must be heated for supercooled conditions.

There is an urgent need for sufficient meteorological data to establish limiting geographical extents and altitudes of ice crystal and mixed clouds in order that standard conditions for testing and approval of aircraft can be formulated.

ACKNOWLEDGMENTS

The authors wish to acknowledge the work done by the Bristol Aeroplane Company Limited, the British Overseas Airways Corporation, the National Gas Turbine Establishment, the Royal Aircraft Establishment, Joseph Lucas Limited, Smiths-K.L.G., the Ministry of Supply, the Air Registration Board and the Low Temperature Laboratory, National Aeronautical Establishment.

CONCLUSIONS

The ice crystal hazard can be minimized in the design stage of an aircraft or engine by careful attention to ducting and passages, avoiding reverse bends as far as possible and certainly avoiding heat on those bends which cannot be eliminated. In the operational stage it is essential that thermal ice protection be controlled by ice detection systems which differentiate between supercooled water and ice crystal clouds, signal the onset of

REFERENCES
(1) Rush, C. K. — *Ice Prevention in a Cloud of Ice Crystals*, NAE NOTE 14, 1956.
(2) Orr, J. L., Milsum, J. H. and Rush, C. K. — *Electro-Thermal De-icing Systems. Their Design and Control*, NAE LABORATORY REPORT LR-70, MARCH 1953.
(3) Rush, C. K. and Wardlaw, R. L. — *Wind Tunnel Simulation of Atmospheric Icing Conditions*, NAE PAPER PRESENTED TO FIFTH GENERAL ASSEMBLY OF AGARD, JUNE 1955.

McCURDY AWARD

The McCurdy Award will be presented at the Annual General Meeting on the 26th - 27th May, 1958.

It is presented each year

To   A Resident of Canada,

For   Achievement in design, manufacture or maintenance related to aeronautics.

NOMINATIONS ARE INVITED

Each nomination should include

  (a)   The name and affiliation of the nominee,

  (b)   Confirmation that he is a resident of Canada,

  (c)   A citation of the particular achievement for which the nomination is being put forward, and

  (d)   The name of the nominator.

The nominee need not be a member of the C.A.I. and the achievement need not have taken place within the last year, though it should be recent.

Nominations should be in the hands of the Secretary not later than the 15th March, on which date they will be handed over to the McCurdy Award Selection Committee.

TRENDS IN COMMERCIAL AIR NAVIGATION†

by N. L. Stoddart*

Trans-Canada Air Lines

Present day air navigation falls into three main categories:

(1) Long Range
(2) Short Range
(3) Approach and landing

To detail the meaning of these divisions, the long range navigation phase is generally considered to be the long over-water flights of from 500 miles up to 2,000-3,000 miles. The short range division covers most short flights from 50 miles to 300-500 miles or flights having stops of these intervals. The approach and landing function may be considered as within 50 miles of a terminal area for discussion purposes.

Now that we have roughly defined the range of these three phases, let us look at the facilities available today to the flight crew of a commercial airline.

In the case of the long range operation, the following equipment will likely be found on board these aircraft for over-water operation.

(1) Dual ADF Receivers
(2) Loran Receiver and Indicator
(3) Sextant
(4) Standby Magnetic Compass
(5) Dual Gyro Magnetic Compasses
(6) IAS and Temp or TAS
(7) Radio Altimeter
(8) Marker Receiver
(9) Dual VOR Receivers
(10) ILS Receivers

In addition to the equipment carried on the aircraft, ground facilities for the various radio aids, such as Loran, Consol and NDB's, are required to provide the necessary information in flight. Normally these long haul flights carry a navigator who will continually use any or a combination of all of the above facilities to correct a dead-reckoning plot which is kept at all times.

The short range navigation problem has been for many years dependent on radio ranges, marker beacons, NDB's and a compass. During the last 5 or 6 years, the use of VOR (Visual Omni Range) stations has been

†Paper read before the Ottawa Branch of the C.A.I. on the 13th November, 1957.
*Radio Navigation Engineer.

implemented on this continent, particularly in the USA and during the last two years in Canada. The use of these facilities is normally carried out by the pilot and no navigator is necessary.

For the approach and landing, additional facilities are available in addition to some of those already mentioned. ILS, GCA and ASR's are installed at many airports.

EXISTING EQUIPMENT

Before going further I should probably outline generally, for those of you who are not familiar with these various aids to navigation, how they function and what is provided.

ADF

The ADF system is an airborne low frequency receiver covering the frequency range of approximately 150 kc to 1750 kc. This provides aural reception of radio ranges, NDB's and Consol, as well as the broadcast stations. Also it will give a relative bearing on the station to which it is tuned. As NDB's and radio ranges are found in most parts of the world on established airways, a pilot or navigator depends a great deal even today on his ADF receivers. Its main disadvantage, however, is its susceptibility to atmospheric conditions and, when most needed, it is often unreliable.

Loran

The Loran system is a long range hyperbolic navigation system operating on a frequency of approximately 2 mc. It requires high power ground stations at desired locations and an airborne receiver and indicators in the aircraft. In addition, the information must be referred to special Loran charts for position information. The range of this system is approximately 300-1,000 nautical miles depending on the time of day or night and, similar to the ADF system, it is subject to atmospheric conditions as well as erratic radio propagation.

Sextant

The sextant I doubt needs much mention except to say it provides the altitude and azimuth of stars, sun or moon, from which your position on the earth can be computed with the aid of standard reference tables. One of the problems here is that the aircraft is far from a stable platform from which to measure such angles accurately. In addition, of course, visual reference is required to obtain this information.

Compasses

I am sure you are all familiar with a magnetic compass. The gyro compass is not new but of recent years has been made more accurate. It is a gyro which is continually slaved to magnetic reference from a flux valve. This unit is normally mounted in some relatively clean magnetic part of an aircraft, such as the wing tips or tail. These systems in present aircraft, if carefully swung, will be accurate within about ± 1°.

I.A.S.-Temperature or T.A.S.

IAS and Temperature or TAS, and in some cases both, are available on present day aircraft. These systems have not proven too accurate due to the corrections necessary; however, 2-5% accuracy would be representative.

Radio altimeters

Radio altimeters are carried on most over-water flights to assist in determining the drift to make good a track. This is determined by measuring the difference between the absolute altitude, as measured by the radio altimeter, and the pressure altimeter set to standard pressure. From this difference and reference to charts and weather maps the drift can be computed reasonably well. This is of particular help when using what is called Pressure Pattern Flying.

Marker System

Marker Beacon System is an airborne receiver operating on a fixed frequency of 75 mc used to receive and indicate by lights when the aircraft passes over a ground marker beacon transmitter. These transmitters are located at most radio range stations in conjunction with the ILS system mentioned below.

VOR

VOR system is a high frequency, short range navigation system operating in the frequency band of 108-118 mc. The range is normally line of sight. This system requires a transmitter on the ground and a receiver and indicating presentation in the aircraft. It is not, however, subject to atmospheric conditions as are the low frequency systems. The information provided in the aircraft gives bearings to the VOR ground stations and steering information to allow one to fly on any radial or direction to or from the station. Much to the pilot's relief, it does not require continual aural monitoring to receive the information, as in the case of the radio range.

ILS

The ILS system is normally considered to be made up of three parts:

(a) the localizer transmitter and receiver, which provide lateral reference to the runway,

(b) the glide slope transmitter and receiver, which provide the vertical glide angle reference, and

(c) the marker beacon transmitters and receiver, which provide distance from the runway at two or three points on the approach path.

In all the above components the transmitters are located on the ground and the receivers and indicating displays in the aircraft.

The localizer operates on a frequency of 108-112 mc, the glide slope on 329-335 mc and the marker, as indicated earlier, on 75mc. The three displays are mounted on the instrument panel to give left-right up-down displacement and the approximate distance to the runway at fixed points.

GCA

GCA is ground controlled approach by means of radar and radio. It consists of two radar transmitters and receivers located on the airport which are used to monitor on scopes the elevation and azimuth of an approaching aircraft. The information is supplied to the aircraft by radio to allow the pilot to make the necessary corrections to his flight path. The main difference between ILS and GCA is that one is presented directly to the pilot in the aircraft and the other to a controller on the ground, who passes the necessary instructions to the pilot. You may, however, have heard many versions of this argument so I will add no more. We use both at present.

ASR

ASR is in service in many large terminal areas today. This equipment has greatly relieved the congestion in busy areas around large airports by allowing the ATC controller to see and direct aircraft more readily than by other slower means.

This will give you a very brief outline of the means at our disposal today to navigate a commercial aircraft over various routes. As you can see, the amount of equipment carried in these aircraft is considerable and as time goes on it increases as new devices and systems are produced. The odd part is that you are never able to remove one box when a new one comes along. To satisfy this situation, equipment manufacturers are attempting to reduce the size and weight of the various systems in new designs so that we do not outgrow the front end of the aircraft. Sometimes we get accused of trying to get in so much that soon the passengers will have to be eliminated.

NEW DEVICES

At present a great number of new devices and systems are being made available or are in the development stage — to mention a few, TACAN, VORTAC, ATC Beacons, Decca, Dectra, DELRAC, Navaglobe-Navarho, Cytac, Doppler Systems, and Inertia Systems.

As you can readily see, we cannot go on putting more black boxes in our aircraft to enable us to get from A to B. In addition, the speed of the aircraft is increasing rapidly. Compare the present speeds of 250-300 mph in conventional aircraft with 500-600 mph in the new jet aircraft we will have in 1960. Also, as more aircraft are flying similar routes today, our accuracy requirements to maintain given tracks are more severe. We, therefore, find ourselves tending to look to self-contained systems which will allow us more route flexibility without the requirement of ground based aids and their airborne components.

Doppler Navigation System

At present we are planning to install a Doppler Navigation System in one of our Super Constellation

aircraft next month. This system we hope will assist us in determining the best way to answer our navigation problems for both long and in some cases short flight.

Doppler radar provides us directly with ground speed and the drift angle of the aircraft. This is information we have never had before except by computing from other sources. When heading information is combined with ground speed and drift, we then know where we are going and how fast. From here on some form of dead reckoning computer is usually connected to tell us where we are at all times and how to get where we want to go.

Before concluding, I should like to outline some of the operational and technical requirements of such a Doppler Navigation System for new commercial jet aircraft.

With reference to the compass system, to be compatible with other components of the system, the heading reference should be accurate to $\pm \frac{1}{2}°$ magnetic or for free gyro operation a drift rate of less than $\frac{1}{2}°$/hour. The Doppler radar should provide information on ground speed to $\frac{1}{2}$-1% and on drift to $\frac{1}{2}°$.

The computer may take various forms from the simplest to the most deluxe versions. We believe it should at least provide us with our present position at all times. In addition, some of the following features should be incorporated depending on the route or area over which the aircraft is operating.

(i) Distance to destination or distance travelled
(ii) Track to destination
(iii) Distance or deviation off track
(iv) Course computations to destination in latitude and longitude
(v) Position reset for error correction with memory
(vi) More than destination inserted
(vii) Automatic variation correction when used with magnetic reference
(viii) Automatic pilot error signal for automatic track flying
(ix) Wind speed and direction directly displayed and inserted in case of Doppler momentary failure.

At present we do not know how many of these and other possible features are required or necessary in these new aircraft. It is obvious, however, that some assistance must be given the navigator or pilot on a high speed aircraft to simplify his ever-growing job of satisfactory navigation along with many other duties. We believe we may expect a system that will be about 1-1½% accurate considering all parts and that it will weigh in the order of 100 lb for the Doppler radar and computer. It is our hope that it will not cost more than $25,000 per system. This may sound like a lot to some of you; however, most manufacturers of these components would like about twice that today. It has been recently stated that the airlines have champagne appetites and beer pocketbooks in this regard.

MID–SEASON MEETING

HOTEL VANCOUVER
VANCOUVER

27th and 28th February, 1958

February 27th	Morning—9.00 a.m. to 12.00 noon .	Test Flying
	Afternoon—2.00 p.m. to 5.00 p.m. .	Operations and Safety
	Evening—8.00 p.m. to 9.30 p.m. . .	T.C.A.'s Vanguard
February 28th	Morning—9.00 a.m. to 12.00 noon .	Electrics and Electronics
	Afternoon—2.00 p.m. to 5.00 p.m. .	Inspection and Maintenance
	Evening—6.00 p.m.	Reception
	7.00 p.m.	Dinner

FOREIGN OBJECTS IN AIRCRAFT, ENGINES AND AIRBORNE EQUIPMENT*

**A Symposium held in Ottawa
on the 24th October, 1957**

SUMMARY

The discussion at the Symposium was recorded verbatim but, because it ranged over a wide field, recurrently referring to many types of foreign objects and contamination, it is unsuitable for reproduction in extenso. In the hope of presenting the discussion in a more useful form, this report has been so arranged that all the significant comments and suggestions on the various topics have been brought together under their respective headings.

Three principal points emerged, namely

(i) the need for improved design to minimize the risks inherent in the inevitable presence of foreign objects,

(ii) the need for improved colour and identification coding of fluids, and
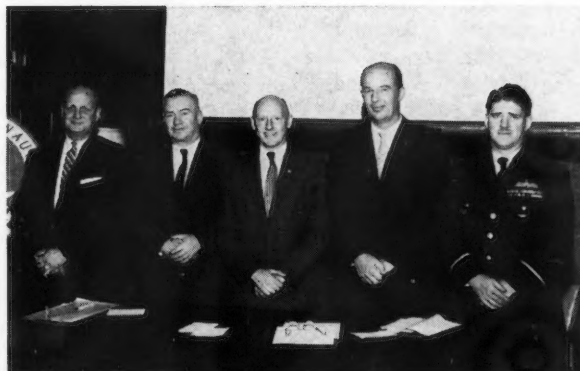
(iii) the need for improved cleaning of runways.

Resolutions on the first two of these were adopted as follows:

(1) That this meeting, being concerned with the reduction of hazards due to foreign objects in aircraft, resolves that a committee be formed under the auspices of the CAI (or AITA) to gather together information on instances in which foreign objects have been found in aircraft, engines and airborne equipment for submission, in the most condensed form possible, to the manufacturers affiliated with the CAI (or AITA); and that upon submission of this information the manufacturers be requested to take positive steps to see that in current and future designs the best knowledge and the best people available are used to check the features which experience has shown to be susceptible to malfunction or damage due to the presence of foreign objects.

(2) That under the auspices of the CAI or AITA a committee be established to study and recommend a colour coding for the supply of aircraft fluids, further identifiable by visual means other than colour.

A Symposium was held, under the auspices of the Institute, in the RCAF Officers' Mess, Gloucester Street, Ottawa, on the 24th October, to consider the question of Foreign Objects in Aircraft, Engines and Airborne Equipment. Mr. H. S. Rees, Chief Aeronautical Engineer, Department of Transport, was in the Chair; 36 members and 17 guests attended, a total registration of 53, whose names are listed in the Appendix to this report.

The meeting was called to order soon after 9.30 am and lasted all day. The framework of the discussion was provided by an Agenda, setting out five specific items, namely, an introduction by Air Commodore G. G. Truscott, Chief Aeronautical Engineer, RCAF, outlining the Problem; an expression of Operational and Maintenance experience by Mr. A. E. Ades, Assistant Director of Engineering, TCA; an expression of Manufacturing

*Report by the Secretary.

RCAF *Photo*

Principal speakers: (l to r) Mr. A. E. Ades, G/C R. C. Hawtrey, Mr. H. S. Rees (Chairman), Mr. D. P. Stowell and A/C G. G. Truscott

experience by Mr. D. P. Stowell, Vice-President, Manufacturing, Canadair Ltd.; a proposal for a Design Specification by Group Captain R. C. Hawtrey, Director of Maintenance Engineering, RCAF; and finally the drafting of Conclusions and Recommendations. After each of these items the discussion was thrown open to the meeting; a verbatim record was taken and this report is a summary of the proceedings.

When the meeting reconvened after the luncheon interval, Wing Commander P. de L. Markham of the Directorate of Maintenance Engineering, RCAF, showed some slides of typical foreign objects found in RCAF aircraft and a film prepared by the USAF, showing the total destruction of a turbine engine by the introduction of a ¼" bolt into the air intake.

A/C Truscott's opening remarks are set out below in full. The remarks of the others taking part in the discussion will be summarized under their respective headings. A/C Truscott said,

"Mr. Chairman, members of the Canadian Aeronautical Institute and guests.

"From time to time, accidents and incidents involving aircraft of the RCAF have taken place which have been found to be caused by foreign objects finding their way into some vulnerable portion of an aircraft. We have had propellers damaged by stones; we have had jet engines damaged by debris picked up from taxi strips and runways; we have had controls jammed by nuts, bolts etc.; we have had electronic and electrical malfunctions due to short circuiting by swarf; we have had fuel system

components damaged by water; and we have had serious malfunctions of hydraulic components due to contamination of the fluid. In a number of cases, foreign objects were missed not only by our own periodic and acceptance checks on aircraft but also by the manufacturers' inspections during construction and assembly. We are most seriously concerned about this apparently ever present hazard which continues to make its appearance in unexpected places in spite of our attempts to eliminate it.

"We have learned of inspection techniques used in the United States during manufacture which go so far as to render all production tools and jigs radio active so that the completed aircraft can be checked over with geiger counters on final inspection and feel that this is indicative of the difficulties being encountered by production inspection services. Altogether we felt that it was time that an attempt was made to assess the extent of Canadian experience with this potentially dangerous situation.

"The Directorate of Maintenance Engineering at Air Force Headquarters considered that the best results could be obtained from a round table discussion with personnel representing the Department of Transport, the aircraft industry, civilian aircraft operators and other interested parties. They hoped that such a meeting would enable a clearer picture of the extent of the problem to be obtained, that the problem would get a fair degree of publicity and that very probably specific recommendations for overcoming at least some of the problems would be obtained. They decided to approach the Canadian Aeronautical Institute and this meeting is the result.

"It is the hope of the RCAF that this meeting will create a precedent for the discussion of problems which are common to all those concerned with the design, manufacture and operation of aircraft in Canada, and that such discussions will result in positive recommendations which may be passed to the appropriate organizations for their consideration and action. In any event, we hope that an informal gathering, such as this, will help to promote a knowledge of the similarity or dissimilarity between military and civil requirements and operations, and will lead to closer contact between those whose activities may involve them in similar problems. We hope you will find this session interesting and enjoyable as well as profitable and that the Canadian Aeronautical Institute will be requested to organize many similar meetings in the future."

FLUIDS

Foreign fluids

Mr. Ades drew attention to the risks of using the wrong fluids in hydraulic, coolant, alcohol, fuel and other systems. He advocated the general adoption of a uniform system of colour and identification coding for containers and filler necks, the wide separation of filler necks where different fluids are used and the use of polarized couplings wherever fluids are transferred under pressure. Mr. Davies (Shell Oil) agreed that a standardized colour coding was badly needed and said that his company would be glad to participate in a committee

to study the matter; he added that the marking of containers was bound up with the types of containers specified by the customers — if these varied, marking machinery varied and it all affected the price.

There was general feeling that the need for a standardized coding was urgent and both Mr. Ades and Mr. Hiscocks (De Havilland) suggested that something should be done soon, without waiting for the establishment of an international standard which might take a long time. Although it was claimed that the RCAF already specify a colour code, it was evident that instances had occurred, both in military and airline experience, where the only exact identification took the form of small markings stamped on the tops of the cans. It was suggested by LCDR Forster (RCN) that NATO already had established a colour code and that there seemed to be no reason why it should not be generally adopted by civil operators, but Mr. Glenn (TCA) and Mr. Gray (CPAL) questioned whether this NATO code was sufficiently detailed to differentiate between different grades. Mr. Gray also raised the point of colour blindness.

The Chairman asked whether the RCAF carried its colour coding from the containers, transfer equipment etc., to the filler cap and lines of the aircraft system. The answer was 'No'.

The Operators, both civil and military, evidently felt very strongly about this matter of colour and identification coding of fluids and, as will be reported later, a resolution on the subject was adopted at the conclusion of the meeting.

Contamination and filtration

There was a great deal of discussion about the cleanliness of fuels, lubricating oils and hydraulic fluids. Mr. Ades referred to the risks of combs, wipers, lighters etc., falling into fuel tanks filler openings, particularly where the operator has to stand over an opening when filling or gauging, and described an effective rubber membrane which had been developed to guard against this hazard; he said that this membrane, through which the filler nozzle could be poked without breaking the essential seal against objects falling in from outside, was preferable to built-in screens, as suggested by Mr. Kuhring (NRC), because screens become obstructed, causing back-up and overflow.

Mr. Ades also mentioned the almost inevitable introduction of particles of metal, bits of seals, flakes of sealing compound and sludge, due to wear or chemical reactions in hydraulic and fuel systems, indicating that adequate filtration could offer the only solution to this class of contamination.

On the subject of water contamination, G/C Hawtrey said that the hydraulic fluid used by the RCAF was a bright red colour, which immediately became clouded when water was present. This change of appearance gave an immediate indication that contamination was present and, for this reason, the RCAF was not nearly so concerned about water contamination as about contamination by solids.

Some interesting data on contaminated hydraulic fluid were given by Mr. Davies. From some samples tested, approximately 80% of the particles lay in the 5 to

10 micron range, 16.3% in the 10 to 20 micron range, 3.9% in the 20 to 30 micron range and the remainder from 30 microns up. Chemically this contamination was 60% silica in the form of red clay, from the ground surrounding the runways; 30% was iron rust and the remainder organic. Some of the samples were very dirty, 1,800 milligrams of contamination per litre. Considered on a particle size basis, with 80% of the particles in the 5 to 10 micron range, this amounts to 1,470,000 particles per millilitre, which is a lot.

The remainder of the discussion under this heading was devoted to two considerations, filtration and the handling of fluids.

Filtration

Mr. Davies said that the suppliers were very conscious of the importance of cleanliness in fuels and hydraulic fluids. Biological filtration techniques had been developed for laboratory use but were not practical for handling large quantities.

It was pointed out by several speakers that, because of the high fuel system pressures and the close tolerances of fuel pumps and control units now in use, fuel cleanliness was of the greatest importance and that many recent failures of fuel system components had been attributed to fuel contamination. TCA reported that, on the Dart, they had dropped their fuel pump life to 650 hours, with an engine life of 1,500 hours; Mr. Ades asked for filtration to 2 microns to overcome this trouble, but added that he knew of no filter which could handle the situation.

From the Manufacturing side, Mr. Picken (Genaire) said that his company had been studying the problem of hydraulic fluid contamination, with a standard of about 5 microns in mind. They wanted a filter capable of passing 10 gallons a minute at 3,000 to 5,000 psi, with filtration down to 5 microns. He added, however, that much could be done to improve the cleanliness of the actual hydraulic units and accessories; it was no use fitting 5 micron filters if the end fittings of the units which the filters were to protect were not properly clean. Improved cleanliness of the units could only be achieved by education of the personnel handling such units and equipment.

Mr. Picken also referred to the problem of filters clogging and in this connection Mr. Hiscocks strongly criticized the use of line filters, which he believed to be called for in some military specifications. Line filters, in his opinion, were more apt to cause trouble than to eliminate it because of the difficulty of inspection and maintenance. He suggested that there was a strong case for having one good filter in the circuit, where velocities are fairly low and located where it is readily accessible to inspection and replacement.

It was suggested by Mr. Garbutt (Aviation Electric) that manufacturers of aircraft should mutually agree on their filtration requirements; the filtration people at present had no clear understanding of what was wanted. Mr. Keddie (Renfrew Aircraft & Engineering) took this up and said that Mr. Garbutt's remarks were very pertinent. His company was engaged in this field and he cited examples of the conflicting specifications, with regard to filter life and standards of filtration, with

which they are sometimes confronted. He went on to hint at a new type of filter soon to become available, with which he confidently expected filtration to a ½ micron to be achieved. In answer to a question from Mr. Ades, Mr. Keddie said that he was referring to the minimum diameter of the particle, not its length. Mr. Hiscocks observed that, using standard hardware, it should be possible to devise a system which was not too sensitive to contamination of that order; he considered 5 microns unacceptable in the average design of hydraulic circuit.

Handling

It was recognized that much fuel contamination could be avoided by the exercise of proper care and cleanliness by those operating the refuelling tenders; Mr. Bellian (Orenda) observed that fuelling was no longer an "unskilled operation". This point was supported by G/C Hawtrey, who reported that when the RCAF had made an officer at each station responsible for all phases of fuel handling, particularly with regard to better housekeeping, the incidence of engine pump failures, which had been having a serious effect upon operations, was materially reduced. The introduction of pressure refuelling was cited by Mr. Whittingstall (TCA) as a means of eliminating a great deal of the trouble, provided attention was paid to the cleanliness of the fuel nozzles and couplings on the aircraft.

Mr. Ades, in his introductory remarks, had made the point that, because of their composition, viscosity and density, turbo fuels tended to carry relatively large quantities of contaminants in suspension and he recommended that fuel dispensing systems should provide long settling periods — at least 1 hour per foot of depth. Later Mr. Davies, on the subject of hydraulic fluids, also stressed the importance of natural sedimentation as a means to fluid cleanliness.
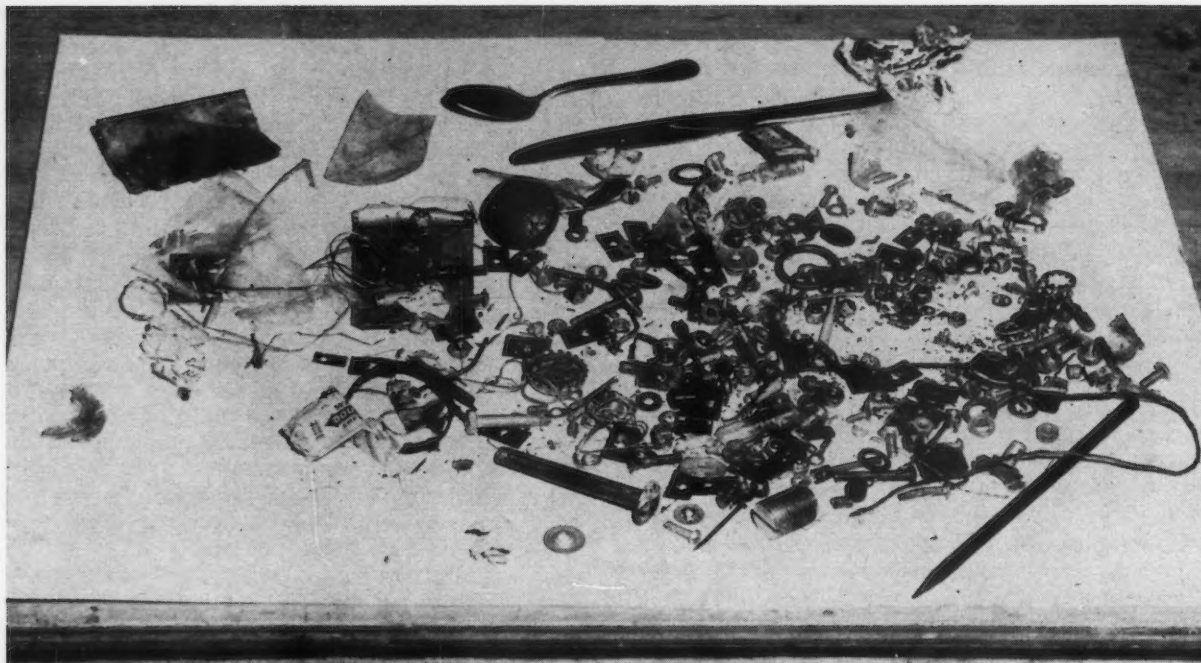
On the subject of lubricating oil, Mr. Whittingstall said that TCA had specified gravity oiling on the DC-8 and the Vanguard, as opposed to the more generally favoured pressure oiling. They believed that the transfer of oil from sealed quart cans, as supplied by the oil company, direct to the aircraft tank, eliminated risk of contamination in the successive handling of oil from bulk storage to ground receptacle, through the pressure hose into the aircraft[a].

TOOLS AND PERSONAL THINGS

In their introductory remarks, both Mr. Ades and Mr. Stowell referred to occasional instances of tools, wipers, bucking bars and the like being found in aircraft. In giving some figures of unscheduled removals of jet engines, Mr. Anderson (Rolls-Royce) mentioned that, of some 177 cases of foreign object damage, 30 had been caused by fitters' tools and things of that nature[b]. Clearly such instances can only be attributed to care-

[a]At the coffee break, Mr. Ranov asked me to explain this point, which he had not quite followed. I explained it and asked him about Russian practice. Col. Roumiantsev replied, as I understood it, that gravity oiling is used on all smaller aircraft but on large aircraft pressure oiling is employed. — Sec.

[b]Mr. Anderson gave the following breakdown of the remaining 147 cases; 2 attributable to ice and snow, 27 to bird strikes, 39 to stones and pieces of aircraft and 79 to unidentified foreign objects.

Some typical foreign objects found in aircraft

lessness and almost every speaker referred to the need for improved housekeeping as the only way to minimize this hazard. W/C Markham pointed out that the RCAF had a particular problem in this regard, because of the constant intake of untrained personnel, who have not developed tidy work habits or a sense of pride in the work they are doing; he suggested that in general civilian operators were able to be more selective in their choice of personnel and could usually employ men with some previous training in the Services. However, Mr. Gray said that the airlines had similar problems; it was simply a matter of training new people not to be careless.

Various precautionary measures were suggested. Mr. Young (Northwest Industries) said that his company had considered issuing tools in the form of kits; for any specific job a mechanic would be issued with a kit and he would not be allowed to take any other tools of his own onto the job. Mr. Luttman (CAI) recommended that all tools held by a mechanic, both his own and those issued to him, should carry his name or some identifying marking and Mr. Garbutt confirmed that within his experience this practice had proved to be effective in reducing the number of tools left in aircraft. Mr. Gray said that his company issued only the major tools and encouraged their mechanics to buy the others themselves, on the theory that a man will be more careful with his own personal property; they also have electric pencils available so that employees can etch their names on their tools, and they are encouraged to do so.

There was also some discussion of the subject of coveralls. Mr. Young said that his company issued coveralls, with a minimum of external pockets, to all shop

personnel and insisted on their wearing them; Mr. Bellian reported that a similar practice had been introduced in the test cells at Orenda Engines, to eliminate the risk of loose articles being drawn out of pockets into engines under test.

In maintenance as opposed to manufacture, G/C Hawtrey pointed out that such devices as the issue of special tool kits and pocketless coveralls could not be so effectively applied. A mechanic is never sure what tools will be needed to tackle any particular trouble, what dismantling will be necessary and so on, and therefore he will usually take all his tools with him.

Quite apart from tools, pencils and the like, used on the job, the discussion brought out a catalogue of many more personal things, such as dentures, car keys, money and lighters. The only real solution seemed to lie in training people to be more careful.

NUTS, BOLTS, SWARF ETC.

RCAF representatives expressed great concern at the recurrent incidence of loose hardware, particularly in smaller aircraft. G/C Hawtrey observed that the airlines did not appear to suffer from this trouble to the same extent and admitted that the RCAF were relatively free of it in their transports. In answer to a direct question from G/C Hawtrey, Mr. Ades said that in over twenty years he could not recall a case of control jamming on a civil aircraft due to a foreign object; the only case which came to mind was one of a gust lock being left on inadvertently. Mr. Whittingstall mentioned an instance on a Stratocruiser, which has a console convenient for pilots to stand coffee cups on; a teaspoon fell through a slot and became involved in the feathering control.

The problem seemed to be directly related to the size, complexity and inaccessibility of fighters and trainers. Mr. Bunnell (Bristol) observed that as military aircraft became more and more complex, the problem would become worse, unless the designers appreciated the hazard and took positive steps to avoid "pockets and shelves" in inaccessible places.

The measures taken by Canadair to ensure cleanliness during manufacture were described by Mr. Stowell and included good housekeeping practices, both on and off the aircraft, careful planning of operations to avoid generating foreign materials and to provide scheduled cleaning operations, the provision of closures and protective covers, particularly for lines and hoses, and the provision of readily accessible cleaning equipment. In this last connection, he produced a small hand vacuum cleaner, operated off the ordinary shop air supply; he said that these were always kept handy and people were encouraged to use them frequently and after every operation. (He condemned the use of a straight air hose, which simply blew stuff about without actually removing it.)

Mr. Davies (Curtiss-Wright) advocated a programme of personal cleanliness on the part of each and every employee. His company had gone to some lengths to impress everybody with the need for tidy habits, the proper use of waste receptacles and so on.

The use of "soap tray" containers was suggested by Mr. Kuhring — something which could be hooked on and which a mechanic could use to hold nuts and bolts etc., rather than balance them on shelves and ledges of the aircraft structure. However, Mr. Stowell did not think this practical; the trouble arises when the mechanic is exercising every sort of contortion to get at an inaccessible place, when he will put things where he can, without groping around for a special container.

Mr. Stowell laid particular emphasis on such small things as swarf, drill cuttings and blind rivet residue, which often cannot be removed by shaking, which adhere to fillets of cabin sealant etc. and which are a great potential danger to electrical systems. He considered the frequent use of the small vacuum cleaners was the best antidote for this type of rubbish. Mr. Mann (Curtiss-Wright) said that his company had had very good results with ultrasonic cleaning of engine parts; it was understood from Mr. Gray that KLM had used the same process in conjunction with solvents to remove dirt sticking to gummy deposits. It would seem that the RCAF were concerned about this problem of nuts, swarf, bits of string etc. adhering to sticky and often inaccessible places; for, as W/C Markham pointed out, such areas cannot always be reached for adequate cleaning by solvents. Mr. Ades felt that special care should be taken in cleaning such areas in the neighbourhood of junction boxes and electrical equipment; in general other areas were not critical.

Mr. Bellian remarked that, so far as hardware was concerned, it seemed to be the expendable items which caused the trouble and said that, at least at some engine manufacturers, such parts as nuts and washers were issued in exact quantities, so that, if a mechanic dropped one, he had to retrieve it in order to have enough parts to finish the job. However, Mr. Stowell said that, in
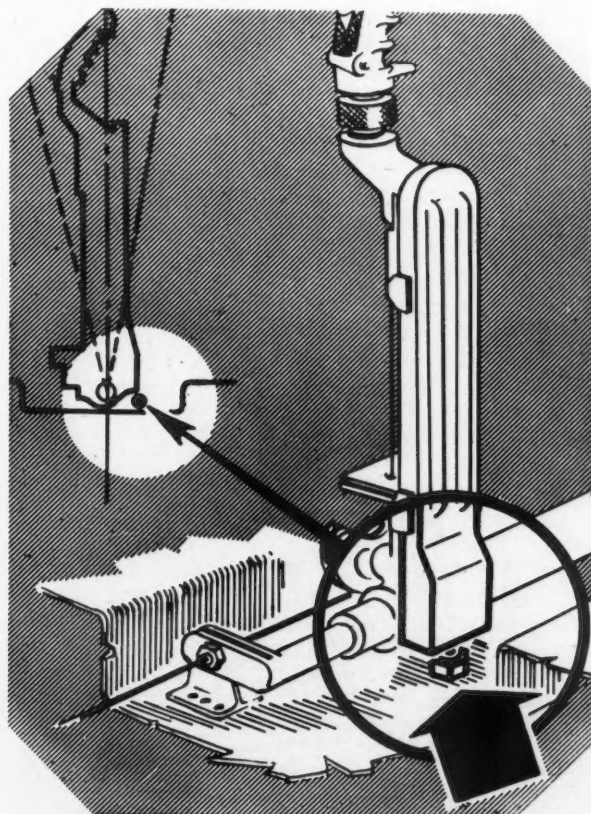
the very large quantities of such items used by aircraft manufacturers, he did not think that a controlled issue was practicable.

On the matter of shaking assemblies to remove loose articles, Mr. Bellian said that Orenda Engines shook each engine and turned it upside down before it was transferred to the test cell. Remarking that the smaller aircraft, fighters and trainers, seemed to give the most trouble, because of their compactness and complexity and because of the negative loadings imposed on them in flight, Mr. Luttman asked whether anyone had ever considered turning them upside down, using a special rig, before they were flown. Mr. Stowell replied that Canadair used devices to shake all the individual components but not the complete aircraft; the best shaking the aircraft got was during test flight, after which a special inspection for cleanliness was always carried out. Mr. Bunnell added that the 'g' loadings imposed in flight often dislodged loose articles not removed by other means — and furthermore that under these loadings such articles were liable to fly about like projectiles, creating a great hazard to the pilot.

In summing up this part of the discussion, the Chairman pointed out that it all boiled down to the exercise of proper care by people working on the aircraft.
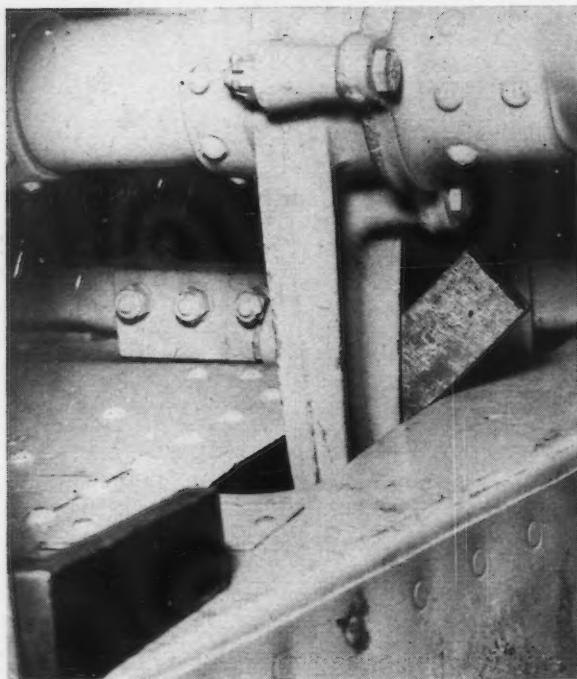
DESIGN

In his introductory remarks, G/C Hawtrey maintained that, however much care is taken in training

RCAF

A nut under a control column

A bucking bar fouling an elevator lever

personnel and adopting procedures to ensure cleanliness, foreign objects will always find their way into aircraft and he called for a design specification laying down requirements for minimum clearances, positive locking devices, guards, seals, filters and so forth, which would prevent interference with controls and other vital parts by such foreign objects as would inevitably occur. He said that his Directorate had studied a large number of existing design manuals and had found nothing specifically governing these criteria; while admitting that individual design organizations might have their own specifications, he said that there appeared to be no general specification in existence.

Mr. Glenn said that his company had such a specification, based on their experience, which they made available to manufacturers from whom they were buying aircraft and, though the manufacturers did not always follow it completely, they usually met most of the points. He offered to submit the fruits of TCA's experience to a common collection. W/C Markham welcomed this offer and said that the RCAF was most anxious that such experience should be made available to everyone.

Mr. Luttman referred to the "Design Notes" put out by the Flight Safety Foundation and questioned whether it was worth trying to duplicate that sort of thing in Canada. W/C Markham had complained that in general the recommendations of the Winterization Experimental Establishment were ignored; people continued to send aircraft to the Establishment year after year suffering from the same defects. Mr. Luttman said that, similarly, the "Design Notes" were probably usually noted, as matters of interest, but their recommendations were not enforced; if they were, a Canadian version might not be necessary.

Other doubts were expressed on the value of such a specification. Mr. Gray, while offering to contribute CPAL experience, maintained that the trouble could not be overcome by design; only by constant training and inspection could hazards from foreign objects be eliminated. Mr. Hiscocks also offered to cooperate but said that generalizations, as inevitable in a specification, would not help; you could not say how big a particle could be tolerated in an hydraulic system without knowing what the system was intended to do. In admitting that the designer had responsibilities in this regard, Mr. Hiscocks felt that the problem could best be overcome by improved education rather than legislation; the trouble was that such principles as the placing of junction boxes on the wall or roof rather than on the floor, the mounting of pulley blocks under the floor rather than on the top where they could become fouled by foreign objects etc., were not passed on by experienced designers to the juniors who succeeded them. Mr. Ades and Mr. Purvis (Orenda) also commented on this point.

Mr. Hiscocks went on to stress that legislation could not invoke better detail design, neither was it desirable to stifle development by insisting on the general adoption of past design features which had proved satisfactory, as was suggested by W/C Markham. He asked that the designers should be given credit for continually trying to improve their products and he welcomed a list of points to be watched, so long as it did not amount to a specification restricting the designers' freedom to handle the points in their own way.

LCDR Nicas expressed a preference for broad specifications laying down, for example, that controls should be so designed that they would not be jammed by foreign objects falling into them, and leaving it to the judgment of the customer to decide whether the requirements had reasonably been met. The Chairman explained that this was, in effect, the policy and scope of the specifications issued by the civil authorities; they specified a broad envelope governing safety and the customers, the airlines, specified the details within that envelope; the RCAF on the other hand was both specifying authority and customer and this gave them a control over their own expenses which the civil authorities did not wish to impose upon the airlines; for, as Mr. Symmons (DDP) pointed out, it would cost money to give contractual significance to the specification proposed by the RCAF.

Reverting to the matter of education, Mr. Hiscocks supported by Mr. Davies of Curtiss-Wright suggested that the RCAF might make available information on the more horrible examples of bad design, to be given wide publicity through such media as the Canadian Aeronautical Journal; the posters issued by the Directorate of Flight Safety might be reproduced for the edification of civilians who would not normally see them. Mr. Luttman confirmed that the CAI would cooperate in such a plan and G/C Hawtrey said that the RCAF would probably cooperate too; however, he pointed out that the conclusions of accident reports were often classified and, as such, could not be made available for publication. Another objection was raised by Mr. McKeown (Canadair) who said that in his experience such publicity campaigns were not effective. They soon lost

their momentum; people looked at the notices without seeing them. W/C Markham added that this, too, was his experience; he felt that all forms of education, though valuable supplements, could not take the place of definite, specified requirements; this was also G/C Hawtrey's opinion.

The role of the field service representative was mentioned by several speakers, notably by Mr. Davies and Mr. Purvis. The designers, they said, could deal only with the weaknesses which they heard about and, for this reason, close collaboration with service representatives was of great importance. Developing this thought, Mr. Glenn referred to a company which had formed a group of former airline personnel, to act as advisers to the designers — and not only as advisers but with authority to make changes; this group had been formed five or six years ago and the results had been remarkable in improving the company's products, from the point of view of maintenance and servicing. Mr. Glenn returned to this point several times; it is of the utmost importance to have people with airline experience situated between design and production, with authority to insist on design changes which they consider necessary. Presumably the equivalent is valid in the military case, but Mr. Glenn was at pains to point out that people with air force experience cannot be relied upon to advise on the maintenance aspects of civil aircraft.

Mr. Whittingstall strongly advocated the development of a check list based on previous experience. He said that, in a recent order, TCA asked the manufacturer to supply a detailed failure analysis; this requirement compels the manufacturer to review all his past defect reports and, since he knows that the customer will have the analysis to check against, he is likely to see to it that every item has been attended to in the new aircraft which he will supply.

The feeling of the meeting was perhaps summed up by Mr. Stowell who said that such a check list, based on the experience of all users of aircraft in the country, might be a reasonable starting point, whereas there were several valid objections to a design manual or specification. W/C Markham had reservations and doubted that such a check list would be used, but Mr. Luttman pointed out that, once the check list existed, it would be the prerogative of any customer, military or civil, to specify it as a contract requirement if he saw fit.
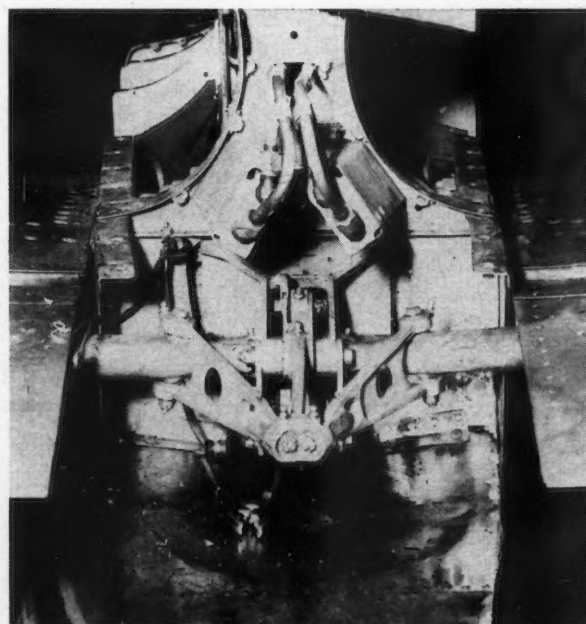
RUNWAYS

A great deal of the discussion was devoted to the ingestion of stones and such things by turbine engines and damage of propellers due to debris of all sorts on taxi strips and runways. W/C Markham showed a USAF film illustrating the catastrophic effects which the ingestion of foreign objects by turbine engines can produce.

Turbine Engines

Mr. Whittingstall reported that, from TCA experience with the Dart, damage to the rotating assembly due to the ingestion of stones etc. was not common, probably due to the relatively small size of the annular intake, but damage to the nose cowl deicer was causing some concern. It was confirmed by Mr. Anderson that the Dart had proved to be fairly free of internal damage;
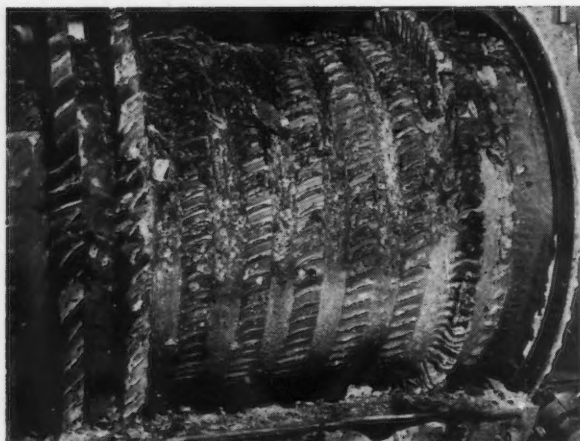
in 1,500,000 hrs Rolls-Royce had records of only three unscheduled removals due to the ingestion of foreign objects and in each case the damage sustained had not been sufficient to cause failure in flight. Again, with regard to nose cowl damage, Mr. Anderson said that the majority of cases were attributable not to stones but to careless handling of ground equipment, engine stands and the like.

However, the story was far more serious with respect to turbojet, as distinct from turboprop engines. Mr. Mann gave some figures arising from work carried out by the Wright Aeronautical Corporation in conjunction with the USAF. 47% of unscheduled removals were due to damage from foreign objects and the USAF estimated that, if the trend continued, 5,000 engines would be removed for this cause during the next twelve months. LCDR Nicas gave some figures for the J34, as used by the RCN and overhauled by the USN. Based on statistics of several thousand engines, 21.4% were rejected to overhaul due to damage from foreign objects, some of which were very severe. Mr. Anderson, referring to Rolls-Royce turbojet engines in heavy aircraft (selected because they do not take off in formation), said that 10 cases of foreign object damage resulting in failure in flight had occurred in 900,000 hrs; of 177 unscheduled removals due to damage found during inspection, 39 were attributed to the ingestion of stones and pieces of aircraft. Mr. Bellian said that, in 1954, 15% of unscheduled removals of Orenda engines were due to foreign object damage; the figure was now down to 9% and of these 8% were due to stones etc. and 1% to pieces of the aircraft. Both Mr. Bellian and Mr. Ades commented on retractable air intake screens; the film shown by W/C Markham seemed to indicate that intake screens provided a fair measure of protection but these two speakers drew attention to their inherent complications, icing hazards etc.

RCAF Photo

A pair of pliers left in a dangerous place

The effect of a foreign object on the compressor of a gas turbine engine

Recognizing that runways and taxi strips can never be perfectly free from sand, gravel and small stones, the engine manufacturers have, of course, tried to increase the tolerance of their engines to the ingestion of foreign objects. Mr. Anderson said that his company had been studying titanium closely and, aside from the increased cost of manufacture, repair and inspection, titanium blades appeared to have some advantages over blades made of steel or light alloy. Mr. Davidson (Bristol) commented that the 50% rejection of J47 engines in the USAF had been considerably reduced by the fitting of steel blades, which offered a much higher resistance to damage than their light alloy counterparts; he also mentioned measures which had been taken to reduce damage to inlet guide vanes due to foreign objects and ice. Mr. Ades, quoting from a Douglas Aircraft report[c], referred to a "Blowaway Jet" which that company had developed; this was a downwardly directed jet designed to prevent the formation of vortices responsible for sucking up material from the ground. But, as Mr. Ades pointed out, the aircraft should not have to carry devices to overcome problems which are primarily attributable to inadequate cleaning of the runways.

Propellers

Mr. Ades gave some significant figures of propeller damage sustained by the TCA fleet between January and July 1957; these were

A/C Type	Tip Ground Clearance		Aerodynamics Braking	Blade Damage Incidents per 1000 A/C hrs
	Inboard	Outboard		
DC-3	12″ Tail up	–	none	.03
North Star	38″	48″	none	.043
Super Connie	21″	43″	Reversing	.0905
Viscount	7″	15″	Discing	.180
Vanguard	32″	48″	Reversing	–

As the Vanguard has the better ground clearance than the Viscount and Super Constellation but also uses reversing, the degree of damage on this aircraft would be expected to be better than on the Super Constellation but worse than on the Viscount.

[c]This very pertinent report was published in the Aeronautical Engineering Review of November, 1957, pp 48-53.

Blade tip ground clearance and the degree of aerodynamic braking employed appeared to be the chief factors in damaging propellers. It was pointed out that stone damage sustained by the reversing propellers of the Super Constellation was an expensive business, necessitating the removal and re-installation of deicer boots on steel blades.

CPAL appeared to have been more fortunate and Mr. Gray said that their instances of propeller damage had not been unduly high.

Mr. Galle (Maritime Central) asked for information on other people's experience with damage to inboard engines and propellers caused by stones thrown up by the nose wheel. He told the meeting that his company, operating on a runway consisting almost entirely of small stones and sand, had suffered a good deal of damage to inboard engines until they had put a stop to high speed taxiing. He asked whether anyone could suggest a way of stopping stones coming up from the nose wheel. In reply, Mr. Whittingstall referred him to Mr. Ades' figures quoted above and pointed out that though TCA had had a severe bow wave problem on the North Star, throwing slush and stones into the inboard engines, the incidence of stone damage was not nearly so high as on the Super Constellation with its reversing propellers. (The key words in Mr. Galle's case would seem to be "a runway consisting almost entirely of small stones and sand" — Sec.)

On the subject of engine location Mr. Beauregard (Canadian Pratt & Whitney) drew attention to the probable advantages, from the point of view of engine damage, of the installation adopted on the Caravelle.

Cleaning

A strong plea was made for improved cleaning of runways and taxi strips. It was recognized that the operators would have to accept some sand and dust but it was felt that the present standard of runway cleanliness was not good enough. Mr. Ades described what he called a hypothetical case — three pounds of nails, three pieces of electrical conduit, one with a box on the end of it etc.; Mr. Whittingstall thought that runways should be kept free of pebbles and stones; LCDR Nicas sug-

A stone jammed in the first row of rotor blades

gested that magnetic sweepers should be used to pick up nuts and bolts; and Mr. Gray referred to "all sorts of foreign bodies and pieces off aircraft" which damaged tires, even though his company seemed to have been relatively free of propeller damage. These instances give an indication of the sort of debris which people had in mind.

LCDR Nicas said that the RCN had discussed the problem with the USN and concluded that magnetic sweepers combined with some sort of high speed vacuum cleaner was wanted. He said that the USAF, alarmed by the high cost of damage to turbojet engines, had developed two huge vehicles, costing $50,000 to $100,000, for cleaning runways; he admitted that the cost was high but it might be worth it when one considered the cost in damaged engines. Mr. Kuhring doubted the value of magnetic sweepers, because of the inevitable presence of materials which are not magnetic; furthermore after any sweeper has been along, an aircraft may take off, breaking ice on the runway and leaving it as a hazard to an immediately following aircraft.

Several speakers drew a comparison between the attention paid to street cleaning and the inadequate measures taken to ensure clean runways. Mr. Taylor (Rolls-Royce) told of an impressive performance which he witnessed at Nice, after the Battle of Flowers, in which the streets ankle deep in flowers, confetti and debris of all sorts were rendered spotless in less than an hour. Mr. Hambly (Aircraft Industries) also referred to city street cleaning equipment which "never gets out as far as the airport".

The Chairman observed that for civil airports, while the cost of cleaning might be small compared with the cost in damaged engines resulting from the present state of neglect, the trouble lay in the fact that one person had to pay for cleaning and another person reaped the benefit.

One interesting observation was made by Mr. Whittingstall. He recalled an NACA report which stated that stones and the like were not picked up by an engine vortex unless they were restrained. A stone lying loose on the runway was likely to be pushed out of the way, and not lifted, but a stone restrained from moving sideways, by a crack or crevice, would be picked up. He

suggested that this narrowed the field and that a programme of reducing cracks and places where things might lodge might go far to ameliorate present conditions.

CONCLUSIONS

The meeting concluded with the carrying of two resolutions, recommending action to reduce the hazards which had been discussed. In this connection, it was submitted by Mr. Luttman that the CAI was not the proper body to take action; he proposed that the resolutions should be brought to the attention of the Air Industries and Transport Association for such action as they might deem necessary and desirable. This was agreed.

The first resolution, moved by Mr. Whittingstall and seconded by W/C Markham, was as follows:

"That this meeting, being concerned with the reduction of hazards due to foreign objects in aircraft, resolves that a committee be formed under the auspices of the CAI (or AITA) to gather together information on instances in which foreign objects have been found in aircraft, engines and airborne equipment for submission, in the most condensed form possible, to the manufacturers affiliated with the CAI (or AITA); and that upon submission of this information the manufacturers be requested to take positive steps to see that in current and future designs the best knowledge and the best people available are used to check the features which experience has shown to be susceptible to malfunction or damage due to the presence of foreign objects."

The second resolution, moved by Mr. Ades and seconded by Mr. Davidson, was as follows:

"That under the auspices of the CAI or AITA a committee be established to study and recommend a colour coding for the supply of aircraft fluids, further identifiable by visual means other than colour."

The third major point, concerning the cleaning of runways, was left in abeyance — apparently by oversight, since it was evidently considered a matter of major importance by all those who spoke on the subject.

APPENDIX

Those present at the Symposium on Foreign Objects in Aircraft, Engines and Airborne Equipment were:

A. E. Ades	Trans-Canada Air Lines
W. R. Anderson	Rolls-Royce of Canada
A. R. Ausler	A.M.C.H.Q.
W. S. Bacon	Computing Devices of Canada
J. Beauregard	Canadian Pratt & Whitney Aircraft Co. Ltd.
W. S. Bellian	Orenda Engines Limited
G. L. Beveridge	Laurentian Air Services Ltd.
E. L. Bunnell	Bristol Aircraft (Western) Ltd.
H. V. Butcher	Simmonds Aerocessories of Canada Ltd.
T. H. Cooper	Canadian SKF Co. Ltd.
C. H. Cotton	Aviation Electric
E. L. Davies	Curtiss-Wright of Canada
R. G. Davies	Shell Oil Co.

C. D. Davidson	Bristol Aero Engines Ltd.
W. F. Delaney	Genaire Ltd.
W/C H. C. Dobbin	R.C.A.F./D.F.S.
LCDR E. R. Forster	R.C.N.
J. N. Galle	Maritime Central Airways
C. D. Garbutt	Aviation Electric
C. H. Glenn	Trans-Canada Air Lines
I. A. Gray	Canadian Pacific Air Lines
W. Hambly	Aircraft Industries of Canada
G/C R. C. Hawtrey	A.F.H.Q.
R. D. Hiscocks	De Havilland Aircraft of Canada Ltd.
H. W. Hows	Northwest Industries Ltd.
J. Irvine	A.F.H.Q.
W. M. Keddie	Renfrew Aircraft and Engineering Ltd.
M. S. Kuhring	National Research Council
P. W. Larsen	Canadian Applied Research Ltd.
F/O R. P. Lloyd	A.M.C.H.Q.
H. C. Luttman	Canadian Aeronautical Institute
S. Macauley	Division of Air Services, Dept. of Lands and Forests, Ont.
W. J. Mann	Curtiss-Wright of Canada
W/C P. de L. Markham	R.C.A.F.
N. McCarthy	Electronics Div., Canadian Westinghouse Co.
H. L. McKeown	Canadair Ltd.
LCDR J. A. Nicas	R.C.N.
J. L. Orr	Defence Research Board
H. B. Picken	Genaire Ltd.
J. T. Purvis	Orenda Engines Limited
N. Ranov	Embassy of the U.S.S.R.
H. S. Rees	Department of Transport
Col. F. S. Roumiantsev	Embassy of the U.S.S.R.
D. P. Stowell	Canadair Ltd.
F/L A. E. Sutherland	A.M.C.H.Q./SACO/ACT
W. Symmons	D.D.P.
L. Thompson	Lucas-Rotax Ltd.
A/C G. G. Truscott	A.F.H.Q.
G. S. Taylor	Rolls-Royce of Canada
S/L M. D. Walker	R.C.A.F./O.F.S.
F. P. Whittingstall	Trans-Canada Air Lines
A. D. Wood	National Aeronautical Establishment
C. C. Young	Northwest Industries Ltd.

C.A.I. LOG

SECRETARY'S LETTER

INTERNATIONAL DEVELOPMENTS

ONE or two recent events have marked the entry of the C.A.I. into the field of international aeronautics and it would be opportune for me to say something about them.

I.C.A.S.

Firstly, as many members will know, a body known as the International Council of the Aeronautical Sciences was established early last year to encourage the exchange of scientific information in all phases of mechanical flight. Every country which had an association dedicated to the advancement of aeronautical sciences and engineering was eligible to participate. Dr. J. J. Green was invited to represent Canada in the initial discussions.

The International Council has laid plans for the first International Congress of the Aeronautical Sciences to be held in Madrid in September 1958. The C.A.I. has been invited to represent Canada on this occasion and furthermore the tentative programme of the Congress provides for a Canadian speaker; other countries asked to furnish speakers include Australia, Belgium, France, Germany, Italy, Sweden, the U.K., the U.S.A. and the U.S.S.R.

It is understood that these International Congresses will take place every two years.

R.Ae.S./I.A.S.

The above-mentioned International Congresses will not replace the Conferences held every two years between the R.Ae.S. and the I.A.S. The next such Anglo-American Conference will be held in New York in October 1959 — it will be remembered that the last one was held in Folkestone last September. This series, which started in 1947, has built up a very high reputation and it is indeed an honour to the C.A.I. that we have been invited to participate in 1959. Participation means that C.A.I. members can attend by virtue of their C.A.I. membership alone: formerly the Conference was restricted to members of the R.Ae.S. and the I.A.S. In addition the C.A.I. has been asked to provide two

speakers and we hope that perhaps a visit to Canada may be included in the Conference programme.

ATTENDANCE AT MEETINGS

Usually our Branch Secretaries in reporting on their meetings refer to their attendances in terms of "members and guests"; they seldom say how many members and how many guests. This month however we publish two reports which are quite interesting. At Winnipeg "there were 50 members and 18 guests present". This is probably a reasonable proportion for a total Branch membership of some 125. However at Toronto "of the 296 people attending, 103 were members of the C.A.I."; the total Toronto Branch membership is about 700.

No doubt there are good reasons behind the Toronto figures. No doubt, if we but knew the breakdown of some of the combined "members and guests" figures, we should find similar unbalance at other Branches. There are three ways to restore the balance;

  (i) to persuade the members to take a more active part in Branch activities, or

 (ii) to persuade the guests to become members, or

(iii) both (i) and (ii).

I.B.M. RECORDS

During the last few weeks, we have been busy setting up I.B.M. records of the membership. These will replace and greatly amplify the mysterious coding which we have used at the bottom left hand corners of our addressograph plates in the past.

I mention this partly because it has taken a great deal of our time and, from our viewpoint, has been a major operation, and partly because we are now in a position to give analyses of our membership which might be useful to Sustaining Members and others.

AMENDMENT OF THE BYLAWS

ANNOUNCEMENT BY THE COUNCIL

A Notice appearing in the November 1957 issue of the Canadian Aeronautical Journal drew attention to two Amendments to the Bylaws proposed by the Council and gave some explanation of them. These Amendments were submitted to all voting members on the 20th November, to be voted on by letter ballot.

As required by Section 3 of Regulation No. 13, the President appointed three voting members, namely Mr. H. C. Luttman, F.C.A.I., W/C J. N. Brough, A.F.C.A.I., and Mr. R. C. Drinkwater, Technical Member, to act as scrutineers and to count the votes.

The Secretary submitted their report to the meeting of the Executive Committee of the Council on the 11th December, 1957. It was noted by the Committee that the majority in favour of each group exceeded two-thirds of the votes cast, thereby meeting the minimum requirements of Section 2 of Article 13; both Amendments were therefore deemed to be adopted.

The scrutineers' report is as follows:

"The voting on the Amendments to the Bylaws, submitted to the membership on the 20th November, 1957, was counted at the Headquarters of the Institute on the 7th December, 1957. The Amendments were voted on in two groups, the first introducing the name "Junior Member" for the grade formerly known as "Technician" and the second effecting a change in the scale of membership dues. The results were as follows:

	Votes cast	In favour	Not in favour
For the first group	1,031	964	67
For the second group	1,029	736	293

Six ballot papers were spoiled.

> H. C. Luttman
> J. N. Brough, W/C
> R. C. Drinkwater"

The Amendments will now be submitted for approval by the Secretary of State. It is unlikely that the formalities will be completed for several weeks and, as intimated in the aforementioned Notice in the November 1957 issue of the Journal, it is not intended to give effect to these Amendments until the 1st April, when the new fiscal year of the Institute begins.

> H. C. Luttman
> Secretary
> For the Council

Dated the 1st January, 1958

APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.

Positions Required

Box 102 **Publications Engineer:** Aero engineering graduate, eight years experience in aircraft industry, requires position of responsibility and chance to widen his experience.

Box 103 **Sales or Administration:** Canadian with 22 years aviation experience in purchasing, sales, administration, seeks challenging position in Sales or Administration.

Positions Vacant

Electronic Engineer: For design on varied projects in airborne and industrial electronics. Work includes analog and digital measuring and control systems, servos and automatic information handling. Applicant should have degree in electrical engineering, engineering physics or radio physics and have at least five years relevant experience. George Kelk Limited, 130 Willowdale Ave., Willowdale, Ont.

Technical Sales Representatives: To work with airframe and engine design engineers in applicating fluid pumps and valves. Candidates should have a good understanding of fuel, hydraulic, pneumatic, oxygen, anti-icing and airconditioning systems. Engineering degree desirable but not essential. Vacancies exist in both Montreal and Toronto areas. Applications should be submitted in the first place by letter to the Aviation Manager, Railway & Power Engineering Corporation, Ltd., P.O. Box 880, Montreal, Que.

BRANCHES

CHANGES IN BRANCH OFFICERS

Since the June issue of the Journal, in which particulars of the Branch Executive Committees 1957-58 were given, there have been a few changes of officers as follows:

Toronto

Mr. W. H. Jackson has been appointed Vice-Chairman in place of G/C E. P. Bridgland who has been transferred to Ottawa.

Montreal

Mr. F. M. Francis has been appointed Secretary in place of Mr. W. B. Boggs.

Vancouver

Mr. F. N. A. Ramsay has been appointed Treasurer in place of Mr. A. F. Coutts.

Edmonton

Mr. J. E. Bristow has been appointed Chairman in place of S/L J. A. G. Diack who has been transferred to Toronto. Furthermore, F/O A. J. Robinson has been appointed Chairman of the Programmes Committee.

NEWS

Edmonton

Reported by C. W. Arnold

November Meeting

The November meeting of the Edmonton Branch was held on the 13th November, 1957. There were 48 members and guests present; Mr. H. Stapleton, Vice-Chairman, presided.

Mr. Stapleton informed the gathering that the Branch Chairman, S/L J. A. G. Diack, and the Programmes Chairman, F/O G. F. Vannier, had been posted to eastern Canada and the executive had nominated Mr. J. E. Bristow to fill the position of Chairman and F/O A. Robinson to be Programmes Chairman. Further nominations were requested from the floor but none were forthcoming and Mr. Bristow and F/O Robinson were unanimously elected.

Mr. J. G. Portlock introduced the speaker, Mr. F. Wicks, Supervisor of Training, Northwest Industries Ltd., whose topic was "Aircraft Accident Investigation". Mr. Wicks introduced his subject by saying that the investigation of accidents to aircraft was a scientific process which must be undertaken by highly trained specialists.

He described the various phases of accident investigation, namely, field work including interviews with witnesses, location of wreckage, aircraft and crew records and laboratory investigation of structural failures and wound up his talk with anecdotes from his wide experience of this type of work.

A film entitled "Search and Rescue T-33" was then shown and after a brief question period, the speaker was thanked by Mr. Portlock and the meeting adjourned.

Toronto

Reported by I. A. Rankin

November Meeting

Mr. J. W. Ames, Chairman, opened the meeting which was held on the 13th November. Mr. J. C. Floyd, Vice-President, Engineering, Avro Aircraft Ltd., introduced the speaker, Mr. W. V. Hurley, Assistant to the President, Avro Aircraft Ltd. Mr. Hurley chose as his subject "The Technical Race between East and West" and his subject was very topical in view of the wide-spread interest in Russia's recent scientific achievements.

The speaker drew attention to an interesting paradox concerning the philosophy of Russia and that of the West. We are prone to think of the individual as having little status in Communist Russia, whereas the Democratic West is supposed to regard the rights of the individual as a fundamental part of our way of life. The paradox stems from the fact that Russia has made some rather startling advances by identifying certain important projects with outstanding individuals and carrying them to a successful conclusion in record time through the concentrated efforts of a relatively small capable team. On the other hand, some projects in the West have lagged partly due to the practice of attempting to get results through sheer force of numbers, with the consequent inefficient use of manpower that such an unsophisticated approach implies — in other words, substituting poorly directed quantity for well directed quality.

Mr. Ames thanked the speaker for his interesting talk. Of the 296 people attending the meeting, 103 were members of the CAI.

Cold Lake Branch

Reported by F/L L. S. Lumsdaine

November Meeting

Nineteen members and ten lady guests were present for the meeting of the Cold Lake Branch held on the 26th November. The Chairman explained why it had been necessary to cancel the December visit to Northwest Industries Ltd., Edmonton, but hoped a similar visit would materialize in the new year. After a welcome to the guests, the film programme commenced and the two films on loan from Shell provided an evening of excellent entertainment. "The Birth of an Oil Field" was the second in the series which is being shown to Branch members during the season. These illustrated films in colour are most popular. The other film was an Australian prize winner, "The Back of Beyond" and is recommended in its class, without reservation. Refreshments and informal discussions completed a successful meeting.

Winnipeg

Reported by D. A. Newey

November Meeting

The Chairman, Mr. C. H. Hovey, opened the meeting with a brief outline of the proposed change in Institute fees which had been proposed by the Council and submitted to the membership for ballot. Proceeding to the main business of the meeting, Mr. Hovey introduced Mr. J. MacLean, Superintendent of Vanguard Production, Trans-Canada Air Lines, who was to address the meeting on the subject "Introduction of Vanguard Aircraft to Trans-Canada Air Lines Operations".

Mr. MacLean outlined the problems encountered by an airline in entering the turbine propulsion field. Vast sums of money were involved and many different types of aircraft were available for study, so that a selection of a type obviously required extremely close analysis. The change poses formidable problems; increased speed, new maintenance procedures and the introduction of new forms of ground testing, maintenance etc., such as X-ray, were becoming necessary for high speed, high altitude operation. Increased ground noise presented a number of problems. Air traffic control, with the increased traffic on the airways and the problems of control around airports, also had to be con-

sidered. Increased complexity of the aircraft and the problems of ground handling of larger aircraft also required consideration. Added to this was the fact that airport facilities were generally not ready for the new aircraft at present under review.

The change to turbine powered aircraft involved a major investment and is the greatest risk which the airlines are having to face in their entire history. It calls for emphasis on planning in the introduction of the equipment cycle. Assessment of the increased needs of the market and evaluation of the various aircraft against the route structure become very important. This makes the selection of the new fleet a major decision of airlines management.

Having decided on the new type or types to be acquired, there comes the problem of their introduction into service. Practically every phase of the operation of the airline is outmoded by the implications of the new equipment. Changes are reflected throughout the entire airline industry and poor performance in any area could result in financial ruin.

It becomes necessary to establish clear balanced objectives which should be founded on basic assumptions. Financial forecasts involving facilities, aircraft procurement, ground equipment and personnel were necessary. Organization and staffing of the airlines for the new type could be approached either by a separate development group dedicated to the new type, or by increasing existing groups already handling existing types. The answer was usually a compromise between these two approaches. In any case, a comprehensive educational programme would be necessary.

In planning facilities for the handling of these aircraft, consideration of location, layout, construction and equipment were fundamental. Spares provisioning programmes should be based on scientific evaluation of requirements. The logistics of dispersal of spares to various centres created considerable problems. Modern methods of data collection and processing, such as microfilm and IBM, will be extremely important.

Ground equipment is no longer a poor cousin to the operation of the aircraft itself and would involve extremely large sums of money. The training of personnel, both flight crew and maintenance, will be of the greatest importance and the extensive use of simulators, not only for flight training but for training of ground staff, will probably occur.

In conclusion, Mr. MacLean mentioned that obviously the execution of the entire programme under close and inspired management supervision would be vital to the successful introduction of these new types.

At the conclusion of the address, the speaker was thanked by Mr. B. W. Torell on behalf of the membership.

Mr. Hovey reminded the members of the forthcoming Branch dance on the 5th December and the meeting then adjourned for the usual coffee, doughnuts and discussion. There were 50 members and 18 guests present.

Ottawa

Reported by F/C F. G. Forrington

Student Section November Meeting

The November meeting of the RMC Student Section was held on Thursday, 28th November, at 4.15 pm. Professor Hetherington of the Electrical Engineering Department at RMC was the guest speaker.

The speaker was introduced by CSL M. D. Thom and completely held the interest of the meeting with his presentation of "Satellites and Problems of Space Travel". The talk included a discussion of some of the problems to be surmounted, such as escape velocity, reentry velocity and the energy required. Professor Hetherington used slides to show some of the theories of space travel which have been put forward.

Following the talk, a film on the development of the Avro Arrow was shown, which was provided by Avro Aircraft Ltd.

With the coming of Christmas exams, it was decided that this would be the last meeting for 1957.

Vancouver Branch

Reported by R. W. Van Horne

December Meeting

The meeting was held in the Officers' Mess, RCAF Station Sea Island, at 20.00 hrs on December 4th, 1957, and was attended by 48 members and guests.

The speaker of the evening, F/L G. MacMillan, was introduced by Mr. H. H. Ollis, who briefly outlined F/L McMillan's background and present duties in the search and rescue and survival training function of the RCAF on the west coast.

The speaker gave the background of the search and rescue function leading up to the establishment in 1946 of the RCAF as the Rescue Coordination Center.

It is interesting to note that in co-operation with tow boat operators on the west coast, the Rescue Coordination Center at Vancouver not only has the facilities of the assigned RCAF aircraft and others, but also some 9,000 vessels plying Pacific coast waters, which gives excellent coverage both for communications and the ability to have vessels near a problem area in short order. We were told that several insurance companies have agreed to guarantee any tow, should it be abandoned for purposes of saving life. In addition to these facilities, mountaineering clubs also work closely with the unit and are coordinated by the Center when dealing with problems requiring their training and talents.

F/L MacMillan informed us that an aircraft crew are in readiness during daytime hours and at an hour's notice at all other times. He also stated that studies of equipment, techniques and communication are going on constantly, with a view to improvement.

A film was shown on the operation of the Coordination Center dealing with a marine rescue.

Mr. T. McLaughlin thanked the speaker for his informative talk on a subject of interest to all of us. The meeting adjourned at 22.10 hours.

MEMBERS

NEWS

F. R. Cordon, A.F.C.A.I., has recently left Orenda Engines Ltd. to manage the new Canadian Sunstrand Aviation Ltd. at Rexdale, Ont.

Dr. G. N. Adams, M.C.A.I., formerly with Bristol Aircraft (Western) Ltd., has moved to Montreal to take up a position as Senior Engineer in the Preliminary Design Section of Canadair Ltd.

M. Arendarski, M.C.A.I., has returned to Canada from Seattle to take up a position as Chief Stress Engineer with Jarry Hydraulics, Montreal.

J. S. Brooks, M.C.A.I., has resigned from CARDE to take up the post of Supervisor, Reliability Control, Defence Systems Management Div., RCA Victor Co., Ltd., Montreal.

DEATH

It was with deep regret that we learned of the death in November of **J. I. Gould, M.C.A.I.,** who was with the Defence Research Board in Washington, D.C.

ADMISSIONS

At a meeting of the Admissions Committee, held on the 10th December, 1957, the following were admitted to the grades shown.

Member

R. L. Adams, Chief Product Design Engineer, Canadian Applied Research Ltd., Toronto, Ont.: *11 Deepwood Cresc., Don Mills, Ont.*

F/S C. J. Bolch, RCAF, Tech. Service Rep. at Standard Aero Engine, Winnipeg, Man.: *515 St. Anthony Ave., West Kildonan, Winnipeg 4, Man.*

J. A. Dunsby, Assistant Research Officer, National Research Council, Ottawa, Ont.: *69 Mark Ave., Apt. 2, Eastview, Ont.*

R. B. T. Field, Supervisor Survey Operations, Kenting Aviation Ltd., Municipal Airport, Oshawa, Ont.

W. P. Harris, Aero. Sales Engineer, Sperry Gyroscope Co. of Canada Ltd., Montreal, P.Q.: *283 Sources Rd., Strathmore, P.Q.*

Capt. D. C. Lamb, Airline Captain, Canadian Pacific Air Lines Ltd., Vancouver Airport, B.C.: *1421 Patterson Ave., South Burnaby, B.C.*

F. G. Massey-Shaw, Engineer, Design of Flying Control Systems, Canadair Ltd., Montreal, P.Q.: *46 Oka Rd., St. Eustache sur le Lac, P.Q.*

Capt. B. A. Rawson, Director of Flight Development, Canadian Pacific Air Lines Ltd., Vancouver Airport, B.C.: *7777 Angus Dr., Vancouver, B.C.*

W. A. Warren, Editor, Industrial Aeronautics, Toronto, Ont.: *R.R. No. 1, Albion, Ont.*

F/O Z. Zikmund, RCAF, Tech. Control Officer, 426(T) Sqdn., Dorval, P.Q.: *5327 Rustic Place, Montreal, P.Q.*

Technical Member

W. N. Gould, Sales & Service Rep., Aviation Electric Ltd., St. Laurent, P.Q.: *582 - 69th Ave., L'Abord a Plouffe, P.Q.*

K. I. M. Hale, (on transfer from Technician)

D. C. Hayward, Aerodynamics Engineer, Canadair Ltd., Montreal, P.Q.: *615 St. Germain Blvd., St. Laurent, P.Q.*

T. G. Heilmann, Tester Gas Turbines and Components, Rolls-Royce of Canada Ltd., Dorval, P.Q.: *1245 Cardinal St., St. Laurent, P.Q.*

R. G. Henly-Lewis, Designer, Avro Aircraft Ltd., Malton, Ont.: *39 Riverwood Pkwy., Toronto 14, Ont.*

N. E. Jeffrey, Aerodynamics Engineer, Canadair Ltd., Montreal, P.Q.: *3360 Maplewood Ave., Apt. 12, Cote des Neiges, Montreal, P.Q.*

A. Klein, Stress and Dynamics Analyst, Jarry Hydraulics, Montreal, P.Q.: *5620 Randall Ave., Montreal 29, P.Q.*

A. C. Mast, Asst. Engineer, Field Aviation Co., Ltd., Municipal Airport, Oshawa, Ont.

W. R. Ratcliffe, Sales & Service Rep., Aviation Electric Ltd., Montreal, P.Q.: *5714 Darlington Ave., Apt. 1, Montreal, P.Q.*

F/O J. E. Watson, RCAF, Staff Navigator, CEPE/AAED, Cold Lake, Alta.: *MPO 503, Grande Centre, Alta.*

Student

M. A. Gray, University of Toronto, Toronto, Ont.: *148 Bloor St. W., Apt. 2, Toronto, Ont.*

D. H. S. Wright, University of Toronto, Toronto, Ont.: *38 - 1st St., Orangeville, Ont.*

Associate

H. E. Henderson, District Aviation Sales Manager, Railway & Power Engineering Corp., Ltd., 197 Eastern Ave., Toronto, Ont.

P. G. Jeffrey, Sales Director, Canadian Applied Research Ltd., 1500 O'Connor Dr., Toronto, Ont.

C. C. Morris, Provisioner, Bristol Aircraft (Western) Ltd., Winnipeg, Man.: *512 Heatherington Ave., Winnipeg, Man.*

MEMBERSHIP OF THE C.A.I.

as at the 31st December, 1957.

Technical	**2066**
Associates	**86**
Total	**2152**

The Technical grades comprise the following:

Honorary Fellows	12
Fellows	31
Associate Fellows	211
Members	1,084
Technical Members	524
Technicians	42
Students	162

BOOKS

Light Scattering by Small Particles. By H. C. VAN DE HULST. John Wiley & Sons, Inc., New York, 1957. 470 pages. Illus. $12.00.

A characteristic of present-day science and technology is the inter-relationship of diverse fields of knowledge and practice. An intriguing example of this productive tendency is van de Hulst's book on the scattering of light. It cuts across many regimes. The illustrations and applications include the following: meteorology, astronomy, chemistry, physics, radar, wind tunnels, blast furnaces, medicine, colloids, X-rays, air pollution and aerosols. The book is a technical reference book to assist those who may need to make calculations involving the attenuation of light by scattering by particles. It is not a textbook because the subject is too specialized and exercises or problems are not posed.

Most of the light by which we see objects and get visual information has been affected by scattering and/or absorption. This book is a treatise on scattering, i.e. reflection of light. It is restricted to situations in which the scattered light has the same frequency as the incident light. Quantum transitions are excluded. Another limitation is that scattering by a diffuse medium, such as a solution of a high polymer, is not treated. Multiple scattering, as in a cloud, involves no new principles beyond those in the book but the problem is a specialized and difficult mathematical one and is not treated. However, references relevant to both these omissions are given. The book does treat thoroughly the theory of scattering of light by one particle. The theory is extended to collections of independent particles, i.e. each particle is exposed to parallel light from the common source and each particle has sufficient space about it to form its own scattering pattern uninfluenced by other particles. Attention is concentrated on light but much of the treatment could be adapted to energy in other parts of the electromagnetic spectrum.

The book is in three parts: (1) theory for particles of arbitrary size, shape and composition, (2) theory for a great variety of special particles, and (3) typical examples. One of the most valuable chapters is No. 18, on scattering and extinction experiments as a tool. A light scattering method may be chosen when any of the following conditions exist: (a) the particle size is of the order of the wavelength of the light to be used, (b) the particles are not readily accessible, as in astronomy or often in meteorology, or (c) a rapid method of routine measures is wanted.

Van de Hulst's book is highly recommended as a reference work and guide to experimental and computational technique for anyone who has to deal with light or other electromagnetic transmission through a medium containing particles.

W/C D. A. MacLULICH

High Speed Aerodynamics. By ELIE CARAFOLI. Editura Tehnica, Bucharest, 1956. Pergamon Press Ltd., London. 710 pages. Illus. $15.00.

Professor Carafoli's treatise covers most of the important topics of the compressible flow theory. The author, who is professor at the Polytechnic Institute in Bucharest and director of the Rumanian Research Institute for Applied Mechanics, has published several books on aerodynamics (most of them on wing theory), some of them as early as 1928 (issued in Paris).

The subject is presented mainly from the mathematical point of view; experimental results are quoted only in relatively few cases. The exposition is clear and particular topics usually are well defined; no excessive assumptions are made as to the reader's knowledge of mathematics and incompressible aerodynamics. The mathematical treatment starts from well stated initial conditions and is worked out thoroughly, including many special cases. The book is easy to read.

After an introductory chapter on basic concepts of vector analysis and thermodynamics, the author presents the fundament equations of inviscid compressible flow and continues with a discussion of steady state one-dimensional flow. The flow conditions in subsonic and supersonic wind tunnels are treated briefly. Next, the linearized two- and three-dimensional theory of subsonic compressible flow is given, including also the hodograph transformations. A very brief and mainly descriptive paragraph is devoted to transonic flow; no mention is made, for instance, of such topics as transonic flow approximation or transonic similarity rules. The rest (and the largest part) of the book deals with supersonic flow. Linearized theories of two-dimensional, axially symmetric and conical flows are presented, followed by airfoil theory (linearized and second approximation), method of characteristics and exact solutions for axially symmetric flows. Theory of wings of finite span is considered in great detail, in fact the presentation would be far too detailed for a book of such a general scope if not for the fact that it includes many original contributions. The author uses preferably the method of "hydrodynamical analogy", that is an analogy between an analytical function which is needed to solve the two-dimensional Laplace's equation into which the potential equation for conical flow has been reduced by Busemann's transformation and the potential function of a fictitious flow in the incompressible region satisfying the same boundary conditions. This analogy is used to solve the supersonic flow around a large variety of wings of finite span, predominantly delta wings. Reverse flow theorems and hypersonic flow are not considered. The book closes with a very short paragraph on linearized unsteady flow. The concept of boundary layer is assumed to be familiar to the reader and discussion of it, as well as of other effects of viscosity, is rather limited throughout the book.

There are remarkably few references, in view of the large scope of the book, which may be due to the limited availability of some periodicals and report series in Rumania. Of special interest may be a relatively large number of references to the Russian literature. A detailed list of contents compensates to some extent for the lack of index of subjects and authors. Printing is good except for quite a few letter omissions.

The comprehensive scope and easy-to-follow style make this book well suitable for students who would be wise, however, not to delve too deeply into the rather lengthy chapters on supersonic flow around wings of finite span, which, on the other hand, constitute a valuable reference source for engineers and aerodynamicists.

K. ORLIK-RUCKEMANN

SUSTAINING MEMBERS

of the

CANADIAN AERONAUTICAL INSTITUTE

1957-58

AEROQUIP (CANADA) LIMITED

AIRCRAFT INDUSTRIES OF CANADA LIMITED

AIR-EX INCORPORATED

ALLOY METAL SALES LIMITED

AVIATION ELECTRIC LIMITED

AVRO AIRCRAFT LIMITED

BABB COMPANY (CANADA) LIMITED

BRISTOL AERO ENGINES LIMITED

BRISTOL AERO ENGINES (WESTERN) LIMITED

BRISTOL AEROPLANE COMPANY OF CANADA (1956) LIMITED

BRISTOL AIRCRAFT (WESTERN) LIMITED

B. W. DEANE & COMPANY

CAMPBELLFORD PRECISION PRODUCTS LIMITED

CANADAIR LIMITED

CANADIAN APPLIED RESEARCH LIMITED

CANADIAN CAR COMPANY LIMITED

CANADIAN PACIFIC AIR LINES LIMITED

CANADIAN PRATT & WHITNEY AIRCRAFT COMPANY LIMITED

CANADIAN STEEL IMPROVEMENT LIMITED

CANADIAN WESTINGHOUSE COMPANY LIMITED

CANNON ELECTRIC CANADA LIMITED

CARRIERE AND MacFEETERS LIMITED

COLLINS RADIO COMPANY OF CANADA LIMITED

COMPUTING DEVICES OF CANADA LIMITED

DECCA NAVIGATOR (CANADA) LIMITED

DECCA RADAR (CANADA) LIMITED

DEHAVILLAND AIRCRAFT OF CANADA LIMITED

D. NAPIER & SON LIMITED

DOWTY EQUIPMENT OF CANADA LIMITED

ELECTRODATA DIVISION OF BURROUGHS ADDING MACHINE OF CANADA LIMITED

ENAMEL & HEATING PRODUCTS LIMITED

FAIREY AVIATION COMPANY OF CANADA LIMITED

FIELD AVIATION COMPANY LIMITED

GARRETT MANUFACTURING CORPORATION OF CANADA LIMITED

GENERAL CONTROLS CO. (CANADIAN) LIMITED

GODFREY ENGINEERING COMPANY LIMITED

GOODYEAR TIRE & RUBBER COMPANY OF CANADA LIMITED

HONEYWELL CONTROLS LIMITED

IMPERIAL OIL LIMITED

JARRY HYDRAULICS

JET IGNITION COMPANY

LUCAS-ROTAX LIMITED

MOFFATS LIMITED (AVCO OF CANADA)

NORMALAIR (CANADA) LIMITED

NORTHWEST INDUSTRIES LIMITED

OKANAGAN HELICOPTERS LIMITED

ORENDA ENGINES LIMITED

PRENCO PROGRESS & ENGINEERING CORPORATION LIMITED

RAILWAY & POWER ENGINEERING CORPORATION LIMITED

ROLLS-ROYCE OF CANADA LIMITED

ROUSSEAU CONTROLS LIMITED

SHELL OIL COMPANY OF CANADA LIMITED

SIMMONDS AEROCESSORIES OF CANADA LIMITED

S. SMITH & SONS (CANADA) LIMITED

SPARTAN AIR SERVICES LIMITED

STANDARD AERO ENGINE LIMITED

THOMPSON PRODUCTS LIMITED

TRANS-CANADA AIR LINES

WALTER KIDDE & COMPANY LIMITED

YORK GEARS LIMITED

put these Westinghouse facilities to work for <u>you</u>

ANALOG COMPUTER—Your design and application problems can be solved more economically in less time at the Westinghouse Computation Centre.

ENVIRONMENTAL AND APPRAISAL LABORATORY—The most complete in Canada. Your products and components can be operated and tested under all environmental conditions and to most military specifications.

ANTENNA RANGE—Especially designed, this Antenna Range has automatic recorders to give antenna design and production testing information in the shortest possible time.

These Westinghouse facilities are a valuable aid in obtaining rapid solutions to your design, production and application problems. They are available to you on a *rental fee basis*.

ILLUSTRATED BROCHURE

Canadian Westinghouse has prepared a special booklet detailing the equipment and the performance of these various facilities. Write to Electronics Division, Canadian Westinghouse Company Limited, Hamilton, Canada, for a free copy of this new booklet.

WATCH WESTINGHOUSE ELECTRONICS

...WHERE BIG THINGS HAPPEN *FIRST*!

Enjoy the New Dramatic Series, Westinghouse "Studio One in Hollywood" on Monday Nights TV.

INSTRUCTIONS TO CONTRIBUTORS

The Canadian Aeronautical Institute invites the submission of papers, articles and technical notes for publication in the Canadian Aeronautical Journal. Following the practice of other societies, the Institute does not pay for contributions.

Authors should prepare their material in accordance with the following directions:

Manuscripts. Manuscripts should be
(a) Typewritten, double-spaced,
(b) On one side of 8½ x 11 white paper,
(c) With wide margins, approximately 1½", and
(d) With pages numbered consecutively.

Manuscripts must be in final form; the addition of material after acceptance by the Institute cannot be permitted.

Titles. The following form should invariably be adopted:—
(a) Titles should be brief;
(b) The name and initials of the author should be written as he prefers; (Rank or title preceding the name e.g. Wing Commander or Dr., should be included but abbreviations of degrees etc., after the name, should be omitted.);
(c) The name of the organization with which the author is associated should be shown under his name; and
(d) The author's position in the organization, referred to in (c) above, should be shown as a footnote to the first page.

Summaries. Each paper should be preceded by a summary
(a) Of 100 to 300 words, (10 to 35 lines, double-spaced),
(b) In non-specialist language, so far as possible,
(c) Stating the main conclusions of the paper.

Sub-Headings and Paragraph Numbering. Sub-headings should be inserted by the author at frequent intervals. Paragraphs should not be numbered.

References. References referred to by the author should be treated thus:—
(a) References should be numbered consecutively throughout the paper;
(b) An allusion to a reference should be indicated by a bracketed numeral e.g. "It has been shown by Dr. T. T. James (7) . . . ";
(c) Direct citation of a reference in the text should be written in full, e.g. "As shown in Reference (7) . . . "; and
(d) References should be grouped together in numerical order at the end of the paper, each showing
first, the numerical designation, e.g. "(7)".
second, the author's name, e.g. "James, T. T."
third, the title of his work, e.g. "Aerodynamics and Ballistics"
fourth, the title, volume, issue no, and date identifying the publication in which it appeared, e.g. "R.B.S. Journal, Vol. 7, No. 77, July 1907".

Thus "(7) James, T. T.,—Aerodynamics and Ballistics, R.B.S. Journal, Vol. 7, No. 77, July 1907."

Footnotes. Comments on or amplification of the text should be given in footnotes, appearing at the bottom of the appropriate pages.
(a) Footnotes should be designated alphabetically and consecutively throughout the paper; and
(b) A reference to a footnote in the text should be indicated by a bracketed letter, e.g. "omitting consideration of the third power (c) . . . "

Figures, Tables and Equations. Reference in the text to
(a) Figures and Tables should be given in full, e.g. "Figure 7", but
(b) Equations should be abbreviated to Eq., e.g., "Eq.(7)" or "Eqs.(5) and (6)".

Drawings. Drawings should be
(a) Individually identified by Figure or Table number,
(b) Not larger than 12" x 16",
(c) In black ink on white paper or tracing cloth, and
(d) Capable of being reduced to 3½" wide without loss of legibility of lettering or other detail.

Photographs. Photographs should be
(a) Black and white, glossy prints, and
(b) Individually identified by Figure number, written on a separate piece of paper affixed to the back: writing on the back of the photographs should be avoided.

Captions. Each Figure and Table should be identified by a caption, in addition to its number, e.g., "Figure 12 Theoretical lift distribution".
(a) The caption of a Table should be shown at the top of the Table;
(b) The caption of a Figure should be shown preferably outside the boundary of the Figure; and
(c) A complete list of Figure and Table captions should be given on a separate sheet of the manuscript.

Mathematical work. Only the simplest mathematical expressions should be typewritten; others should be carefully written in ink. Mathematical work should be
(a) Uncrowded—plenty of space should be provided to accommodate directions to the printer—,
(b) Repeated on a separate sheet of the manuscript, again uncrowded and with plenty of space around each expression,
(c) Clearly written to distinguish between like symbols. e.g. between zero and the letter 'o', and between Greek and English letters of similar form, and
(d) Accompanied by a manuscript "index" of the Greek letters used in the paper, identifying each letter by a name, e.g. "α—alpha".
In addition the following practices should be adopted:
(a) Simple fractions appearing in the text should be shown with a solidus, e.g. $A/(B+C)$ rather than as
$$\frac{A}{B+C}$$
(b) Complicated expressions should be identified by some convenient symbol, if necessary to avoid repetition of the whole expression; and
(c) Complicated subscripts and exponents, and dots and bars over letters or symbols should be avoided.

Symbols and Abbreviations. Consistency is important;
(a) The symbols recommended in the American Standards Association "Letter Symbols for Aeronautical Sciences" ASA Y10-7—1954 should be used wherever practicable; and
(b) Abbreviations of units should be shown in lower case without periods, e.g. lb, mph, bhp, etc.

Mailing. Papers should be mailed to The Secretary, Canadian Aeronautical Institute, Commonwealth Building, 77 Metcalfe St., Ottawa 4, Canada.
(a) Drawings and photographs may be mailed rolled or flat, not folded;
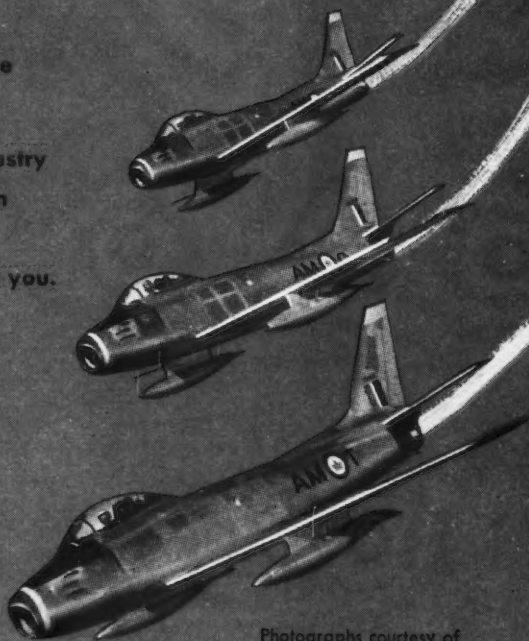(b) Manuscripts should be mailed flat.

Bristol's Winnipeg plant undertakes considerable modification work for the R.C.A.F.'s CF-100, Expeditor, and B-25 aircraft. Components for the Navy's CS2F-1 are also manufactured here.

30 YEARS EXPERIENCE in aircraft design and construction contributes to the quality of floats manufactured at the Winnipeg plant.

With 175,000 square feet of floor space and 600 employees, this Bristol plant in Montreal North is the largest aero engine repair and overhaul plant in Canada.

Final assembly of a commercial airliner's turbo compound engine takes place at Bristol's Montreal Plant.

No. 5 in a series

THIS IS *BRISTOL* →

IN CANADA

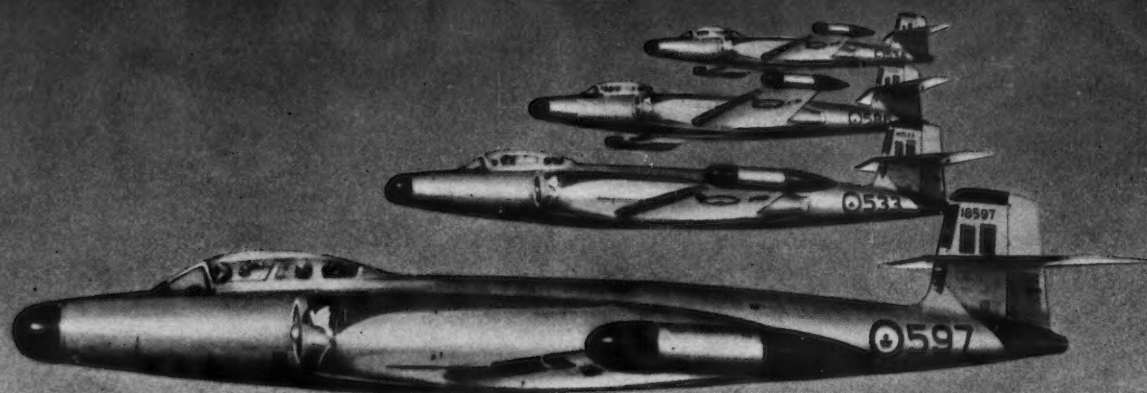The Bristol organization in Canada comprises three extremely modern plants.
The plant at Vancouver International Airport, (see photo below), overhauls and repairs engines for R.C.A.F., R.C.N., C.P.A. and P.W.A.
The Winnipeg company, largest aircraft plant in Western Canada, modifies and repairs aircraft for civilian operators and the R.C.A.F., makes aircraft and engine components, manufactures floats for the de Havilland aircraft.
The extensive repair and overhaul plant in Montreal North handles piston-type engines, mainly for R.C.A.F. and T.C.A.

BRISTOL AERO ENGINES
(WESTERN) LIMITED.

THE BRISTOL AEROPLANE COMPANY OF CANADA (1956) LIMITED MONTREAL • WINNIPEG • VANCOUVER • MEXICO CITY

ON GUARD IN CANADA...IN EUROPE...
AND FOR THE FUTURE...THE AVRO ARROW

From the first flight of the Mark I CF-100 in 1950, the development and performance of this all-weather interceptor for the Royal Canadian Air Force has won for it the role of front line defender in North America and Western Europe.

The Avro Arrow, recently unveiled, begins an intensive pre-flight testing program. Under development for the interception role of the RCAF in the new North American Defence Command, the Arrow will have supersonic mission capabilities.

AVRO AIRCRAFT LIMITED

MALTON, CANADA

MEMBER: A. V. ROE CANADA LIMITED & THE HAWKER SIDDELEY GROUP